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UNIVERSITY OF ALBERTA

THE SCIENCE, TECHNOLOGY AND SOCIETY APPROACH: A PHILOSOPHICAL CRITICISM

BY

CAROL SEATTER

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF EDUCATION

IN

PHILOSOPHY OF EDUCATION

DEPARTMENT OF EDUCATIONAL FOUNDATIONS

EDMONTON, ALBERTA

SPRING 1991

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ABSTRACT

Secondary science education is in need of a revival. Alberta Education, for the past five years, has been in the process of producing a revised science curriculum with a Science, Technology and Society (STS) emphasis. Science 10 is soon to be piloted in Alberta high schools. The rationale of its Course of Studies (Final Draft) is founded upon the belief that such a program will promote greater relevancy for the student, eliminate the current negative image of science and produce informed decision-makers.

This thesis makes the assumption that science education should in some way reflect the actual process of scientific activity. It examines the nature of science from a philosophical perspective. The philosophers of science most in evidence in this work are Thomas Kuhn, Karl Popper, Imre Lakatos and Paul Feyerabend. Once the nature of science is examined, the new STS Science 10 Course of Studies is critically analyzed for evidence of a study in the nature of science. The technological and societal aspects of the new Science 10 are found wanting in their reflection of pure science. This approach to science education is viewed as an extension of Thomas Kuhn's "normal science", with its focus on a particular paradigm. Such scientific activity is validated by the theoretical framework of the current paradigm of scientific thought. It lacks an innovative and creative focus and negates a critical inquiry.

Science studies should reflect Harvey Siegel's

"pluralist" science education. Scientific experiment and evidence must be tackled with an open mind, recognizing the fallibility of scientific knowledge and allowing for the possible validity and fruitfulness of rival ideas. Science students should put into practice Schwab's "fluid" inquiry, involving the development and appreciation of alternative concepts and frameworks, as compared to Schwab's "stable" inquirer who merely accumulates a doctrinal education. The STS Science 10 reveals shades of both the "normal scientist" and the "stable inquirer." A refocusing of science education from a philosophy of science perspective attempts to reverse this current fashion in science education.

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Chapter One

INTRODUCTION

The philosophy of the new Science 10 Science, Technology and Society (STS) program is pertinent to the direction in which senior high science is taking in Alberta. The new program which has been presented throughout both urban and rural school districts is not being received well by teachers or administrators. It is important to assess carefully the positive and negative aspects of such a course as Science 10 as it is the pre-requisite for all further senior high science, chemistry, biology and physics courses. The philosophy and rationale of the Science 10 is indicative of how educators are seeing science and how they intend to redesign the disciplines of chemistry, physics and biology as well.

What is the role of a philosophical criticism of a science program? What can be acieved by such an undertaking? Firstly, the content of policy documents on science education reflects the views of special interest groups and other pressures groups extraneous to philosophical reflection. At the same time, embedded within a policy document regarding science education lies an assumption of the nature of science and the importance of science in the overall context of education. Therefore, its rational assessment depends upon the cogency of its philosophical underpinnings.

A philosophical perspective allows one to delve into the nature of science and of technology, examine that which each comprises and evaluate whether or not the aspects of technology and society are essential components of the understanding of the nature of science. This thesis does not delve into the areas of curriculum implementation and inherent problems of teacher training. It is restricted to a philosophical analysis. Once it is established what the nature of science is that is, how it progresses from one theory to the next and the differences between science and non-science -the new STS science program is examined in the light of this discussion. The two mainstreams of philosophy of science are centred around the basic philosophies of Thomas Kuhn and his major work The Structure of Scientific Revolution and Karl Popper and The Logic of Scientific Discovery, as well as advocates of both. This thesis uses a foundation of these current philosophies of science as an indicator of the process of science and scientific activities. Science 10 is examined in the light of the philosophy of science.

Chapter two comprises a close look into the nature of science; how science progresses and is judged to be successful, which requirements make a science a science and what is the difference between science and pseudo-science. This "Nature of Science" chapter examines the evolution of thought within the philosophy of science as it has progressed from the naive inductivist viewpoint, still much in evidence in our science texts and teaching in the schools, to the philosophies of Thomas Kuhn and Paul Feyerabend's Against Method are also explored.

Karl Poppper's insight into the nature of science displaces the emphasis of theory being proven by evidence to one of theory being disproved by evidence. Popper sees science progressing through the scientist's presentation of conjecture and the exposure of those conjectures to refutation. The falsificationist perspective is followed by a look at a more complex nature of science. This expansion of the concept of the nature of science includes the philosophy of Thomas Kuhn from his work The Structure of Scientific Revolutions. Here the emphasis is on Kuhn's separation between the work of the "normal scientist," taking place within the confines of a particular theoretical domain, and that of the "revolutionary scientist." The community of scientists finally recognizes anomalies within the paradigm in which they are working and abandons the old and takes on the new. The relativism of Kuhn's perspective is brought out by an examination of his ideas about theory choice. No one, according to Kuhn, can make a judgment about the worth of a particular domain of scientific endeavour, unless they are fully immersed in the program themselves.

Chapter two proceeds through a discussion of the determination of progress in science. This leads to an examination of Kuhn's presentation of incommensurable paradigms and the implications for science and the teaching of science of such a view of scientific progress. As well, Popper's theory of scientific change is discussed in the light of scientific progress. The views from Israel Scheffler's, Science and Subjectivity, Larry Laudan's Progress and its Problems and John Passmore's Science and its Critics are introduced as a means of presenting a critical analysis of these opposing viewpoints. The advantages and disadvantages of the work of Paul Feyerabend and Imre Lakatos are presented as further indication of how perspectives within the philosophy of science have been shifting.

The differences between what is believed to be science and non-science is examined in light of the various philosophers of science. The emphasis in this section is on Karl Popper with his determination that anything defined as a science must have the potential to be falsified. Stephen Toulmin's views are put forward here in light of his presentation of different goals between that of science and a non-science. Toulmin speaks of the goal of science as being an **explanatory** one as opposed, for example, to that of technology which has a **practical** goal.

In summary, Chapter Two finds the nature of science to be found in a recognition of and searching out of anomalies within current acceptable theory in the context of critical inquiry, as well as the openness of the scientist to honest dialogue with those of conflicting viewpoints. In the words of Israel Scheffler, scientific theories guide by "orienting us selectively toward the future - yet they do not blind us to the unforeseen" (Scheffler, p. 44).

Chapter Three is entitled "The Nature of Technology." This chapter presents a glimpse at the differences between pure science and applied science (technology). It begins by presenting the similarities and differences between the two, historically and currently. There is a distinction made between Toulmin's explanatory procedures of natural science and practical procedures of technology. Both disciplines are presented as rational but rational according to different goals and procedures.

For a practical grasp of a specifically Alberta technology, an example of a natural gas processing plant is utilized. A surface look at the major processes occurring within the plant and the scientific principles in operation is given. The social and economic goals of such a technology are emphasized. This multiplicity of requirements involved in the desired "state of the art" technologies is held in comparison to Kuhn's normal science which is focused upon the activities of the current paradigm.

The ethics of technology is looked at briefly in respect to the current negative image of science. Arguments from Feyerabend, and John Passmore indicate that science can be vindicated from the evils of technology. "The scientist's heart is pure", and technology is neither "his creator nor under his control" (Passmore, p. 27). Decisions and actions which directly affect our universe, and those who live within, are restricted to the realm of technology.

What effects can education have towards producing citizens who are more aware of the possible evils of technology and subsequently will contribute positively to society for this cause? Chapter three includes a look at Michael Scriven's "Education for Survival" and the teaching of science through controversial issues. The conclusion is that a study of technology will not contribute to a greater understanding of science. One looks to society and its attitudes and values for an honest evaluation of and justification for the role of technology, one does not look to science. If it is an understanding of science which produces more informed citizens, it will not be found through the teaching of technology.

The fourth chapter of this thesis examines the final draft of the proposed STS Science 10 Course of Studies. The chapter begins with an overview of STS approaches world wide and their rationales. Fensham's work from Monash University in Australia is presented because of his influence in advocating the social nature of scientific work and the social application of science. A look at STS believers in Great Britain reflects the perspective that a study of technology would capture for the students the truth about the positive aspects of science and that it is only through the study of applied science that ideas and devices are examined which improve the quality of life.

The rationale for the STS program focuses on the importance of relevance. Informed decision-making comes to life in the science classroom through proposed solutions to "real" life problems (Collette and Chiappetta, pp. 235-238). Educators must no longer look within science for a solution, they should be looking outwards from science to society to see how science is applied (Fenshan, p. 69).

Chapter four includes an overview of the Science 10 final draft of Course of Studies. It looks at the breaking down of each of the four units into four columns entitled Major Concepts, Science Knowledge, Science Skills and STS Connections. A breakdown is given of some specific major concepts and the STS connections included to emphasize and illustrate these concepts. An interesting example is found on pages 22 and 23 associated with the concept "Matter has a well-defined underlying structure." The proposed STS connection for the teaching of such a concept is found in the words "discuss the merits of spending public money on investigating atomic structure." Many similar examples are given and discussed critically in light of the nature of science and technology.

Relevance and motivation are looked for within the new Science 10 as it is firmly believed that the inclusion of social relevance found within the STS science program is essential for the production of scientists and informed citizens. The unity of science is examined in light of the major themes of change, diversity, energy, equilibrium, matter and systems to be found within Science 10. The Course Rationale and Philosophy states that there exists a fundamental unity of thought in the enterprise of science which needs to be reflected in the science curriculum. A discussion of this statement is presented through the works of Graham Wallas, James Conant, Michael Martin and Joseph Schwab. A critical survey of the unity of science is studied in light of the philosophies of Kuhn, Lakatos and Feyerabend. According to the naive inductivist or even falsificationist, this simplified view of science rings true. Opposing as their viewpoints are, all three aforementioned philosophers deny such a perspective of science and its activities. Through stressing the aspect of the unity of science, rather than the diversity of science, students are again encouraged to see scientific knowledge in a vacuum. The conclusion of chapter four describes the proposed Science 10 course as one of merely adding distraction and confusion to the study of science. The STS connections do not contribute to the understanding of science, only to a narrow focussing upon current social issues.

The final chapter ties the discussions of all previous chapters together in the presentation of a senior high science course with a totally different emphasis from that of the STS science 10. Both the current science courses as well as the proposed STS science courses are found wanting. The present science classes are largely centred around the naive inductivist approach to science. As a result memorization of fact and formulae are the only fruits of labour. The future STS science contains features of Kuhnian science - that is, a narrow focus upon current issues. Scientific knowledge is relative to a particular paradigm and therefore lacks true critical thinking and open-mindedness towards opposing theories past and present.

Chapter Five includes a promotion of a senior high science course (whether it be entitled science, biology, chemistry or physics) utilizing aspects of a philosophy of science approach. Examples are given of work produced and implemented in this area by Patricia Burdett and Colin Gauld. This refocusing of science education involves being open to new reasons. As advocated by Michael Martin and Harvey Siegel, students of science should be taught a number of theoretical approaches in a domain of research. They should be exposed to different theoretical approaches and learn to work with different viewpoints.

Harvey Siegel makes a distinction between different types of science students. He describes Joseph Schwab's "stable enquirers" who are similar to Kuhn's normal scientists, pursuing scientific experiment within a particular mind set. In contrast, Siegel presents Schwab's "fluid enquirer" who bears similarity to Kuhn's revolutionary scientist and who is exposed and committed to what Siegel calls a "pluralist" science education. (Siegel, p. 108)

Siegel's pluralism involves the "role of reasons" in science and this is to be found within the context of the philosophy of science. Within this domain are found the nature of evidence, the relation between evidence and theory, the evaluation of the strength of evidence, and the role of evidence and reason in testing and in theory choice. (Siegel, 1988, p. 112)

A discussion follows regarding the appropriateness of the goals of the STS science - increased relevancy of content, reduction of the negative image of science and production of informed decision-makers. All of these goals are discovered to be more applicable to a philosophy of science course than to an STS one.

In conclusion the new STS science 10 program does nothing to alleviate the current problems inherent within the present Alberta high school science studies. It is truly a science education for the "Normal Scientist." It simply becomes, in Popper's words:

> activity of the not-too-critical professional: of the science student who accepts the ruling dogma of the day; who does not wish to challenge it; and who accepts a new revolutionary theory only if almost everybody else is ready to accept it - it becomes fashionable by a kind of bandwagon effect. To resist a new fashion needs perhaps as much courage as was needed to bring it about. (Popper, p. 52)

Real science often involves starting your own band.

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Chapter Two

THE NATURE OF SCIENCE

An understanding of the nature of science requires a knowledge of three integral elements. These essential components of science and scientific inquiry include the concepts of scientific change, scientific progress and the demarcation between science and non-science. A focus on these perspectives will expand our picture of the true nature of science; that is, these three elements comprise what there is that is important to know about science.

Canadians in the 1990s no longer believe the same "truths" or believe the same facts to be true about the world around them as they once did. We have changed the chemistry of our children's vaccine, have changed the process of cooking our foods, have expanded our knowledge of the universe and have even altered our conception of matter itself. How does this change occur? Is there some universal element or elements involved in theory change that is essential to an understanding of the true nature of science?

Theory Change

There are several philosophers of science who have radically changed our viewpoint of the essence of science over past decades and it is their diverse and often conflicting presentations that we will be examining throughout this chapter with the objective of arriving at some conclusions of our own. The philosophers' works most in evidence throughout this chapter are those of Karl Popper, Thomas Kuhn, Imre Lakatos and Paul Feyerabend.

Let us take a look at a moment in history for an example of scientific theory change, science in action. Joseph Priestley's chemical world was founded upon a mystical substance named phlogiston. The nature of the atmosphere, the process of combustion and even the manifestation of different colours were all seen by scientists of Priestley's day as owing their existence to phlogiston. For example, when a metal (which was believed at that time to be a compound) burns, phlogiston is released. Combustion is seen as a decomposition process and air as an independent element which serves as a receptacle for the escaping phlogiston.

Lavoisier, on the other hand, can view the same sorts of happenings, in this case a metal burning, and interpret the process as one of composition, that is a combination of a particular gas, oxygen, with a metal to produce a compound. The concept of what was believed to be a substance named phlogiston is now believed to be a gaseous element named oxygen, of different chemical and physical properties. With the "redefining" of the element oxygen and a recognition of its role in numerous areas of life comes a **change** in scientific theory. Combustion is perceived as something quite different since the day of Lavoisier. No longer perceived as being a process of decomposition, it became recognized as quite the opposite; a process of synthesis. What is the nature of this chemical theory change: The phlogiston theory, or the belief in the existence of phlogiston, has been falsified. Does studying science involve the defining of what combustion is or was; or is it examining the transition between different theories or combustion? Different philosophers of science interpret theoretical change in different ways. Thomas Kuhn speaks of scientific change through "Revolution." The change which occurs involves a transfer of belief from one paradigmatic mode of inquiry to another. A group of scientists encounters enough difficulty working within an existing infrastructure that they "sees the light!" A conversion, or in Kuhn's words, a "Gestalt Switch" takes place; and with it a new scientific mode of inquiry is "born again." This is the Revolution - an abrupt break with the past and a new game begins; this time with different objectives, rules and procedures.

Within a particular paradigmatic mode of inquiry, scientific activity proceeds under the guise of what Kuhn has named "Normal Science." Normal Science develops experiments, hypotheses and theories which conform to the existing infrastructure; it does not question or rebel against the status quo. This is where the most essential part of scientific activity occurs, Kuhn advocates: BEFORE the revolution. The essence of science for Kuhn then is NOT change, it is the fine-tuning of a particular theoretical concept. The process of inquiry occurs, critical inquiry does not. Questions are raised but only in the context of current theory. No new questions are being asked. When change does occur it is via "conversion" and not through critical analysis and discussion. From Kuhn's description of the happenings which occur within a transference from one "paradigm" to the next, critical thinking appears to be as absent from the period of his "extraordinary" change as it is during his period of Normal Science. This change seems to imply a sudden change of mind, a "gut feeling" as opposed to a rational evolving of ideas. Communication between paradigms is impossible according to Kuhn because of the "incommensurability" of conflicting paradigms. The very meaning of terminology is transformed as well as the style of reasoning for scientific anomalies (Hacking, pp. 66-74). Scientists involved in the playing of different games cannot reasonably discuss and compare their goals and objectives - they are holding different cards.

> Do we, however, really need to describe what separates Galileo from Aristotle, or Lavoisier from Priestley, as a transformation of vision? Did these men really see different things when looking at the same sorts of objects? (Kuhn, 1970, p. 120)

The evidence against the phlogiston theory of combustion was the empirical evidence of observation - a metal burning weighed more after than before the combustion took place.

This quantitative observation presented one of many potential anomalies. Priestley's answer was to contend that really mass was not a major consideration in the physical sciences and anyway phlogiston, because of its "spiritual" element possesses a negative weight and always finds its Aristotelian natural place above that of water and earth. This Kuhn would describe as Normal Science in action.

In spite of his immersion in the phlogiston paradigm, Priestley was the first to isolate oxygen and to recognize the fact that another form of a gaseous substance other than air existed. however, this anomaly called oxygen did not convert Priestley to a new paradigm of scientific thought. This discovery and understanding of the gaseous element oxygen had the potential to change Priestley's vision regarding the process of combustion and from there on the entire paradigmatic realm of scientific thought in this domain. he explained to others, and to himself, that the air was modified by phlogiston and that oxygen was really **dephlogisticated** air - pure air with a higher amount and rate of burning than normal air. That is, he made excuses for the evidence! The scales from his eyes were not lifted. This is how Kuhnian normal science works at its best: the communitie's adherence to the old paradigm as long as it is rationally or even irrationally possible, followed by a sudden irrevocable switch to the new.

The philosophy of science advocating scientific change through revolution portrays the nature of science as one lacking critical thought and discussion and virtually closed to reason (Siegel, pp. 94-5). Science is advanced through a change in direction of one's thinking to the extent that the new is cut off from the old way of thinking. There are many philosophers of science, however, who see the history of science revealing scientific change in a manner quite the opposite to that of Thomas Kuhn's "fits-and-starts" theory.

Karl Popper protests against Kuhn's incommensurable paradigms of scientific activity largely because the competition between paradigms cannot be resolved by proofs (Popper, pp. 51-56). Kuhn claims that there can be no evaluation of a paradigm without total immersion within it. If the leap from one paradigm to another is incommensurable there certainly can be no one left to evaluate the old, let alone put it to the test. And if there are some old paradigm loyalists to be found they would be unable to convincingly test the old criteria in a manner in which advocates of the new would be able to comprehend.

This relativistic view of scientific progress limits one's understanding of the direction which science has taken. Has there been progress or has there not? Popper is arguing that if the scientific activity of a particular paradigm cannot be assessed as either progressive or non-progressive, then it is not really scientific activity at all. In this sense Popper is saying that the competition, or sense of direction, cannot be assessed if paradigms involve incommensurable scientific theory. Change in scientific theory occurs through the method of "bold conjecture and criticism" (Popper, pp. 51-54). The essential changes occur in science simply because a scientist is able to hold up his or her theories to this very criticism which Kuhn eliminates from his concepts of scientific change. It is the concept of "falsification" which Popper advocates as the essence of the nature of science. Granted we are all "prisoners of our theories" in that what we believe and what we have once experienced influence the very way we look at and interpret our world; BUT it is always possible to "break out of our framework any time" through critical thinking and enter a "better framework" (Popper, p. 56). Therefore, critical discussion and a comparison of the various frameworks is always possible. In this way science is always changing. Popper describes an evolutionary, as opposed to Kuhn's revolutionary, process of scientific change.

Scientific change can be seen more clearly from an examination of the problem of conceptual change. Socrates once said that the problem of rationality is equal to the problem of keeping men (and women) OPEN TO REASON. Without this openness to reason truth would yield to the "belief of the loudest-mouthed," soundness to the ideas of the "most respectable" and validity to the "intellectual methods of the most persuasive" (quoted in Toulmin, p. 43). Perhaps there is some overlap here between Socrates' "disagreement decided by the balance of power and not principles" and Kuhn's process of conversion to the next incommensurable paradigm. Kuhn, by spreading the impression that even in science no way exists to judge a theory except by the number and vocal energy of its supporters, endorsed the credo of student revolutionaries, that "truth lies in power" (Baum, p. 7)

> Concepts, like individuals, have their histories, and are just as incapable of withstanding the ravages of time as are individuals (Kierkegaard quoted in Toulmin, p. 51).

Our concepts change with exposure to new evidence. Our concept of anything consists of the term used to describe something (phlogiston), the meaning used to interpret it (mystical substance which is released during combustion), and the actual picture one holds of the object itself (the substance being emitted as smoke during combustion). For another example, gold is the term I use to describe a yellow coloured metal and the object itself looks like a discoloured piece of rock. As the meaning of the concept of gold is transformed, so is my understanding of this object transformed. Once I begin to conceptualize gold as not simply a yellow metal but with a specific atomic number and powers of reaction with aqua regia my concept, or what I actually look for when I look for gold, changes. Toulmin argues that Popper, Kuhn and Lakatos all share a similar starting point in scientific inquiry: that is that "conceptual change has continued to be more or less an anomaly for them" (Toulmin, p.

479). An anomaly occurs which reveals a possible misconception about something or other. Conceptual change starts with the recognition of the inconsistency and a searching out of novel explanations for the inconsistency.

Progressive Theory Change

Change, however, is not enough for a closer inspection of the nature of science; it is the **direction** of change which is crucial. Scientific theories can "progress" from an old theory I to a better theory II via revolution or the evolutionary process of inclusion and accumulation.

Thomas Kuhn challenges the view that the history of science is a story of unremitting progress marked by the steady accumulation of individual discovery and invention, whether by the process of proving or disproving (Kuhn, 1970, p. 2). Kuhn presents a challenge to the over-simplified approach to science as depicted by the naive inductivist and falsificationist. However, Kuhn's concept of progress in science is difficult to pinpoint. All science, according to Kuhnian philosophy, stems from a period of "pre-science;" a period during which there is no foundational consensus on theories, assumptions or methods. This state progresses to a period of scientific history named the aforementioned "paradigm." A paradigm constitutes the working together of scientists whose research is founded upon an agreed theoretical bedrock. A community of experimentation and problem-solving emerges which constitutes Kuhn's period of "Normal Science."

Kuhn's incommensurability of paradigms allows for NO CONNECTION between the old and the new. Accompanying this break in the chain of the growth of knowledge is a blurred image of the notion of progress. There is really no way of knowing whether one paradigm is more advanced than the next. If terminology and "style of reasoning" become incomparable from one paradigm to the next only participants immersed in a particular paradigm can interpret or evaluate the worth of scientific endeavour within. In Kuhn's view, Copernicus' and other novel theories not only changed the meanings of words but in effect "changed the world that presented itself for theoretical interpretation" (Baum, p. 5). From the example of the phlogiston-oxygen paradigm switch, once could say with Kuhn that Lavoisier's meaning for the word "combustion" was irrevocably different from Priestley's definition and that accompanying this change in meaning was a change in interpretation of the world around him. Consequently, old theories were not in any real sense falsified as Popper would have it. Kuhn contends that it is only in periods of "extraordinary science" leading to scientific revolution that the basic theories of mature science incur Popperian criticism. Closer examination reveals that even at this brink of revolution, the activity of critical thinking is doubtful.

Although Falsificationists leave us an unrealistic picture of the history of science and present too simplistic and inaccurate an account of scientific theory (which will be discussed later), Popperian science does tackle the problem of scientific progress. Karl Popper's Falsificationism describes scientific progress as a feedback process. The formula is as follows:

P_1--->TS--->EE--->P_2

The initial problem (P_1) is followed by the trial solution proposed (TS) and then on to error elimination (EE) and finally, the resulting situation with a new problem (P_2) (Magee, pp. 65-66).

Knowledge, then, grows not by a process of proving items to be true, but by the "weeding of error elimination" (Popper, np. 50). For Popper conjectures and refutations are the path to progress in science. Falsificationism identifies the critical attitude with a successful scientific attitude. Science takes a step in the right direction by rejecting hypotheses that were falsified and by holding to those which the severest tests corroborated. Both Popper, and as we shall see, Lakatos, agree that inductivism is found wanting. In no way can particular facts provide good reason for more general statements or claims about the future (Hacking, p. 114). Science does not accumulate a store of finally proven, settled truths, but by bold conjecture and self-criticism it can and does improve its theories' approximation to the truth.

A closer examination of the philosophies of Kuhn and

Popper will reveal that both fall short of an acceptable, accurate account of scientific progress.

The Kuhnian history of science portrays a disruptive, non-accumulative pattern of advancing science. There has been a paradigm shift: a CHANGE has occurred, but is it a PROGRESSIVE change? Or is one simply left with many different descriptions of the same things? Kuhn has stated in his "Reflections on my Critics," that whatever scientific progress may be, we must account for it by examining the nature of the scientific group, discovering what it values, tolerates and disdains (Kuhn, 1970, p. 238). Toulmin, in his article entitled "Criticism and the Growth of Knowledge," depicts this concept of "Normal Science" as nothing less than a "foundation of dogma" (Toulmin, 1970, p. 39).

Israel Scheffler offsets the effectiveness of Kuhn's theory through a revelation of its many inconsistencies. Kuhn stresses incommensurability and yet writes that "any successful new theory must somewhere permit predictions that are different from those arrived from its predecessor" (Kuhn, 1963, p. 96). This difference, Kuhn affirms, could not occur if the two were logically compatible. Scheffler points out that Kuhn is trying to deny the cumulativeness of theories, but in the course of his denial allows a predictive criterion as relative to their comparative evaluation. He opposes the notion of falsification, that is progress in science, through the discovery of anomalies within current theory, but introduces "crises" and "anomalies" with parallel functions. Kuhn downgrades the relevance of deliberation to paradigm change and still claims that a new paradigm will solve problems that the old one could not. Finally, Scheffler points out that Kuhn criticizes "cumulative" science, yet speaks of being able to "preserve" a great deal of the most concrete parts of past achievements. Scheffler sums up his concerns over Kuhn's social relativism by affirming that "optimism is not a mere philosopher's dream" but an operative and controlling ideal of scientific practice (Scheffler, pp. 89-90).

Popper would agree that science is essentially a problem-solving activity. However, within the falsificationist philosophy problems that are refuted or disconfirmed are no longer worth of scientific consideration (Laudan, p. 37). Every theory ever devised has anomalous instances, yet both Kuhn and Popper would have the experimenter abandon their theories when anomalies occur. How can one be sure of pinpointing the exact source of the problem? Would it not be jut as impossible to **disprove** a theory once and for all as it would be to **prove** a theory once and for all as the naive inductivist does? John Passmore argues that it is not just a matter of history that scientists often ignore anomalies; objections, and apparent refutations. it is "not just a result of their being psychologically weak or under sociological pressure" that apparent contradictions or anomalies are temporarily ignored. It is necessary for them to do so (Passmore, pp. 110-111). If this appears to the reader to be an irrational process, that is the ignoring of contradictions while researching a theory, then we must all agree then that science is irrational! The anarchist, Paul Feyerabend, adds his support to this denial of falsification as a means of progress in science. "There is not a single rule, however plausible, and however firmly grounded in epistemology," he tells us in Against Method, "that is not violated at some time or other." This is not out of ignorance or carelessness but because such violations are **absolutely necessary** (quoted in Passmore, p. 113). Feyerabend states tnhat there are many instances when it is profitable to contradict well-established and generally accepted experimental results (Passmore, p. 113).

A philosopher who has contributed a great deal towards the understanding of the development of science is Imre Lakatos. Lakatos would agree to some extent with Kuhn, although he is a "refined" follower of Popper, that there is no magical method of instant rationality - no water tight way to take a piece of scientific work and decide upon its merit, as both inductivism and falsificationism would have us believe. Lakatos turned to "on-going" science; to the progress of scientific research. he describes the progress of the history of science through the advancement of the "Research Programme." As opposed to Kuhn's paradigmatic concentration on one particular theory, the Research Programme encompasses a network of interrelated theories and methodologies, taking place over an extended time period.

A Research Programme is like a game with evolving rules. Science embodies a Research Programme which includes not only the basic laws but also auxiliary hypotheses and initial conditions. The rules of the game include a "hard core" of basic theories which are preserved through a negative heuristic. To some measure Hanson's problem of "theory laden" observation is tackled here in that Lakatos describes a hard core which is fixed temporarily while the searching out of anomalies in investigated thoroughly within the auxiliary realm of the Science Programme before any attempt to truly question and perhaps reject the hard core of belief is made. Where evolution occurs is within the protective belt of auxiliary hypotheses which are subject to change in light of experimentation (Chalmers, p. 30). Once can determine the direction the programme has been moving over time. To be a "progressive" Research Programme, as opposed to a "degenerative" one, the stratagems adopted to accommodate different experimental findings should always be progressive.

To Lakatos to be progressive means to be content-increasing through the anticipation of new facts. A new theory II must predict novel facts not foreseen in the old theory I. Programmes are "empirically progressive" if some of these predictions pan out. Lakatos cautions that one must take budding Research Programmes leniently as it may take decades before they get off the ground and become empirically progressive. He tries to avoid the same mistake as Popper by allowing for falsification to adjust the protective belt and reveal anomalies, at the same time protecting the hard core of the program from being abandoned at every whim. Preservation of the hard core of the Lakatosian Research Programme does provide the necessary stability for science to progress. If the predictions of observations are inconsistent with theory, the entire program is not abandoned as in Popperian science; the protective belt alone does the stretching. Lakatos provides a necessarily slow choice between the results of research programs, rather than an immediate choice by falsification of basic theories. This is often the choice that scientists do make (Baum, p. 11).

Lakatos' theory, however, could hardly be utilized as a guide to scientific progress by prospective chemists and physicists as it has been produced strictly by a reproduction of the past. How do we know that science did progress in the most progressive way" All we know about are the success stories that did occur. We cannot tell if a Research Programme of science is progressive until after the fact. Also, if the decision of whether a programme is a fruitful one or not may take decades and if many albeit progressive programmes may slip into a degenerative mode before progressing once again, how do we decide where to do our research?

It will be useful at this point to take a closer look at the philosophy of Paul Feyerabend. Feyerabend favours Lakatos' model of scientific progress over that of Thomas Kuhn. He goes so far as to compare Kuhn's Normal Science tradition to that of "organized crime" (Feyerabend, p. 200). This idea is in line with Popper's discussion of the Normal Scientist as simply having been taught badly in a dogmatic spirit; that is, a victim of indoctrination (Popper, pp. 52-53). Feyerabend questions why Kuhn's "pre-science" with its feature of competing theories is regarded as inferior to Normal Science. In direct opposition to this limiting perspective, Feyerabend promotes what he calls "proliferation." Proliferation means that there is no need to suppress even the most outlandish product of the human brain. Everyone may follow his or her inclinations and science will profit as a result. This philosophy, one Against Method, promotes a sense of freedom and autonomy essential for scientific innovation. A generally successful theory will be retained as a basis for research, despite occasional conflicts with observation, until a better theory appears. "Tenacity" means to develop one's inclinations and then to develop them still further! Don't throw out the baby with the bath water!

Proliferation is an idea Feyerabend takes from J.S. Mill in his work entitled On Liberty. Science flourishes, contends Feyerabend, when there is a multitude of hypotheses in the field. Science has a tendency, Feyerabend often affirms, to harden into dogma and treat as abnormal alternative views to those which are currently acceptable. This is in direct opposition to the conditions of scientific progress as the history of science "soon reveals how often the scorned view turns out to be the one that is finally fruitful" (Feyerabend quoted in Passmore, p. 112). There is no set of fixed rules with which science can be said to progress. There are always variations within any scientific inquiry of any scientific discipline which could lead to a new discovery of increased knowledge in science. There are principles only as in Lakatos' Research programmes.

In one sense Feyerabend's "anything goes" is the opposite to Kuhn's "anything acceptable goes." With Kuhn's position, such rich areas of scientific research enhanced through creativity and intuition would be completely annihilated from Normal scientific activity. However, Feyerabend's anarchistic theory of knowledge and scientific progress, although it does leave room for both creativity and intuition, needs some essential qualifications to keep science proceeding on course. Critical inquiry is the only avenue through which allowing the proliferation of ideas in the advancement of science can take hold and move forward. The next problem is to define exactly what is meant by critical inquiry.

Frankena writes that John Dewey is the "apostle of the method of reflective enquiry" (Frankena, p. 143). Action and thought should not be habitual, says Dewey, but instead what must become habitual is the use of intelligence. To be automatic and spontaneous about reflective thought, as Dewey thinks of it, means a "habit of using the method of reflection whenever we sense a problem and of trying to sense a problem whenever there is one" (Frankena, pp. 141-144).

There are two components of reflective inquiry then: that of dealing effectively with problems or anomalies which one encounters in one's everyday work and the searching out of additional problems which may arise only through an honest search for them. This reveals aspects of Feyerabend's tenacity and proliferation. This kind of critical analysis and inquiry plays a key role in the nature of scientific endeavour.

Feyerabend successfully argues against method insofar as he has given a strong argument for the fact that it is not advisable for the choices and decisions of scientists to be limited by the rules laid down by or implicit in such methodologies of science as that of Popper and Kuhn (Chalmers, p. 136). Although Feyerabend concurs with Kuhn on the idea that two theories can be incommensurable and uses classical mechanics and the relativity theory as an example, he speaks of the interplay between "tenacity and proliferation" as an essential feature of the actual development of science, that is, the active interplay of various tenaciously held views. These scientists would not be doing merely puzzle-solving activity but incorporating critical inquiry into their dialogue (Popper, p. 207). Proliferation does not start with revolution, as in Kuhn's view, but precedes it. In short, Feyerabend argues against the false assumption that there is a universal scientific method to which all forms of knowledge should conform and that this assumption plays a detrimental role in our society, especially in light of the fact that the version of science usually appealed to and understood by most is some crude empiricist or inductivist one (Chalmers, p. 141). There is no one method by which science progresses.

Science or Non-Science

An examination of the nature of science must include the element of demarcation. How can one recognize science from non-science or pseudo-science? Definitions vary drastically within the world of philosophy of science. Science is the process of proving theories to be true through inductive reasoning. Science is the rigid testing of theories to falsify them as stepping stones in the progress of science. Science is that which occurs mostly through the puzzle-solving of ardent followers of a current scientific theory and then abruptly undergoes a "Gestalt Switch" to a different, incompatible theory and begins again. You can tell if the activity is true science because it has progressed through the formation of Research Programmes in which auxiliary components surrounding the core theories have been pulled and stretched to adjust to contradictory findings. An activity can be safely named scientific no matter what ideas, hypotheses or theories are utilized as long as the individual is left free to advance science in his or her own manner, science is "anarchistic enterprise" (Feyerabend, p. 17).

Can all these various definitions hold true for the defining of the nature of science? Is it possible to describe what one determines to be science when really it is one aspect of science, for example physics, instead? Or can we say with Lakatos that the dividing line between science and non-science is identical to the line between "rational activity and irrationalism" (quoted in Hacking, p. 120). Lakatos takes this further with his suggestion that the growth of scientific knowledge might provide a demarcation between the rational irrational aspects of science. That which grows in knowledge, then, becomes rational. This leads us to the question asked of many scientists. Where do astrology, Marxist historiography and psychoanalysis fit into the picture: are they science or not?

From his work entitled The Logic of Scientific Discovery, Karl Popper writes a section on "The Problem of Demarcation." He expresses an awareness that Falsificationism rules out the process of induction as a valid method for establishing scientific theories. As a result, Popper states that it may be said that he has eliminated "the barriers that separate science from metaphysical speculation" (Popper, p. 34).

However, Popper advocates that the inclusion of inductive reasoning does not provide a suitable "criterion of demarcation" (Popper, p. 34). Sir Karl's problem seems of particular relevance for those involved in the enterprise of science and science education today because of the empirical inductive brand of science practised in the classrooms of our secondary schools. The science portrayed in text books of the 1990's is still the same.

Popper distinguishes between those of positivist beliefs in the past and the present. Older positivists admit as "scientific or legitimate" only those concepts "derived from experience" - sense experience, that is, such as sensations, impressions, perceptions, and visible or auditory memories (Popper, p. 35). Modern positivists admit only those statements which are reducible to "atomic" statements of experience. However, the criterion still demands an "inductive logic" (Popper, p. 35). Our convention of inquiry is scientific, according to Popper, if and only if our experience "has been submitted to tests, and has stood up to tests" (Popper, p. 39). He argues that it is not through verifiability but falsifiability that one finds the criterion of demarcation. For example, it could be said by Popper that Lavoisier's oxygen revolution occurred because he made a deliberate search for contradictions within the phlogiston theory. He re-did the experiments of Priestley, Black and Cavendish in order to refute the current theory. As a result, he was able to unlock the puzzle of combustion, recognize a metal as a single element and oxygen as a gas distinct from air. Kuhn could argue that finally Lavoisier had "seen the light" and with this conversion the paradigm of Aristotle's chemistry based on four basic elements of earth, water, air and fire was abandoned. Popper would argue that this could never have occurred within the "Normal Science" tradition where all activity focused on the existing doctrine, as in the case of Priestley who stuck to his belief in the phlogiston theory in the face of much conflicting evidence. Do we not call the work of Priestley scientific simply because he did not throw out his falsified theory? Is Lavoisier more of a scientist than Priestley? I think not. The science is in the arnriving at a viable theory.

Feyerabend argues that alternatives, referring to his preference for proliferation, increase the empirical content of the views that happen to stand in the centre of attention and are, therefore, "necessary parts" of the falsifying process (Feyerabend, p. 48). This allows for the "breathing space" that methodology must grant for the ideas we wish to consider and of which Feyerabend and Lakatos both agree.

Can one agree with Toulmin that "A person's rationality is displayed by how his [or her] beliefs change in the face of new evidence and experience?" (quoted in Phillips, p. 17). Israel Scheffler agrees with Hanson in affirming that our "categorizations and expectations" do guide by "orienting us selectively toward the future - yet they do not blind us to the unforeseen" (Scheffler, p. 44). Lavoisier's beliefs did change, in spite of the paradigm in which he was immersed, but only through recognizing and working with what appeared to be conflicting theories within his research (Kuhn, pp. 118-120). He was not only receptive to the potential within anomalies, he sought to produce some of his own! Sir Humphrey Davy again changed the picture of chemistry drastically through consistent testing in many areas of solution chemistry, before he recognized that hydrogen gas, not oxygen as Lavoisier believed, was responsible for the powerful properties of acids (Mason, pp. 454-457). These are continuous, progressive steps in the progress of science, although not examples of Kuhnian paradigm shifts.

Stephen Toulmin defines a collective human enterprise which takes the form of a

> rationally developing discipline, in those cases where men's [and women's] shared commitment to a sufficiently agreed set of goals or ideals leads to nthe development of an isolable and self-defining repertory of procedures; and where those procedures are open to further modification, so as to deal with problems arising from the incomplete fulfilment of those disciplinary ideals (Toulmin, p. 399).

The crucial element in a collective discipline, Toulmin argues, is the recognition of a sufficiently agreed goal or ideal, in terms of which common outstanding problems can be identified. Where this common goal is an explanatory one, the discipline is a scientific one (Toulmin, pp. 359-364). In agreement with Toulmin, one could say that in order for a problem to be seen as a problem some sort of "agreed goal or ideal" must exit amongst those working in similar scientific endeavour.

In summary, the nature of science could be found in a definition such as the following: science involves the recognition of and searching out of anomalies within current acceptable theory in the context of critical inquiry, the openness of the experimenter and theorist to honest dialogue with scientists and non-scientists with conflicting viewpoints, and the ever-expanding knowledge base in the world in which we live.

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Chapter Three

THE NATURE OF TECHNOLOGY

This chapter will pursue an examination of the nature of technology and try to reach a conclusion regarding the compatibility between pure science and technology. Traditionally, the theoretical or pure component of science has been separated from the **craft** or applied aspects of science; pure science is of interest only to the intellectually elite, applied science for the everyday person. This viewpoint would appear to be obsolete today with the wide embracing of technologies for use in society, however there remains an important dividing line. Although the relationship between science and technology is an obvious one, the separation still exists between the two disciplines and therefore it is worth the effort to examine the difference. Chapter two dealt with the nature of science. In chapter three we will examine what we mean when we say "technology", that is, what is the **nature** of technology?

Science and Technology: Similarities and Differences

It is important at this point to take a closer look at the history of "practical" or "technological" science. Bertrand Russell advocates that science, ever since the time of the Arabs, has had two functions: (1) to enable us to **know** things, and (2) to enable us to **do** things (Russell, p. 29) The Greeks were only interested in the first of these.

> They had much curiosity about the world, but, since civilized people lived comfortably on slave labour, they had no interest in technique. (Russell, p. 29)

Interest in the practical sciences came first through a fascination with superstition and magic. The Arabs wished to discover the philosopher's stone, the elixir of life, and how to transmute base metals into gold. In pursuing investigations having these purposes, they discovered many facts in chemistry, but they did not arrive at any valid and important general laws, and their technique remained elementary (Russell, p. 29). Curiosity and science went hand in hand. The quest for knowledge determines the process of science, pure science.

To say that technology is **not** science and that it does not contribute towards a study of the nature of science is not to say that the nature of technology is not rational or that technological advance is not vulnerable to diverse checks and balances, as is the path of scientific progress. Toulmin, from his book entitled Human Understanding, defines technology as that which is outside of the realm of science and uses terms such as "craft" and "applied science," when speaking of the nature of technology. It is important to note that not all technology is applied science, although much of the technology of educational interest can be described as such. Secondly, the technology or applied science utilized in education would be limited to the processes and techniques which are part of the child's environment.

Although the historical development of technology can be described in terms closely parallel to those that apply to scientific disciplines, the difference lies in the goals inherent within technology. As opposed to the aspirations of science being theoretical in nature; the **ideals** of technology are practical ones. A developing technology does not comprise of evolving network of theories and concepts, but of "recipes, designs, and techniques; manufacturing processes and other practical procedures" (Toulmin, pp. 364-366). Therefore, there is a separation between the **practical** procedures of technology and **explanatory** procedures of natural science. There is a separation between the discovery and refining of scientific laws and processes, and the directing and manipulating of those laws into devices and techniques. Toulmin argues that the difference in endproducts has nothing to do with the rationality of changes themselves. Can one argue that the conceptual changes in science are rational where the technological changes are not? What marks a scientist's work as rational is his or her readiness to "think, explore and criticize" new concepts and arguments and techniques of representation as an effective manner in which to tackle the problems which arise within his or her domain of scientific study. There is in technology, as well as science, a justification for procedural change (for example, economics or public demand) and therefore the choices are rational ones, at least to some degree.

As in science, so too does the advancement of technology suffer from certain hindrances to rationality. Institutional conservatism, interests and financial influence of dominant individuals, reckless or overcautious management and excessive rivalry between professional generations can all lead to mismanagement of available knowledge and irrational decision making.

Technology is simply the societal application of pure science, however its development and introduction for use within society is not entirely dependent on the latest scientific discoveries. Again, it is essential that the gap between the explanatory nature of natural science and the practical application of technology is emphasized. One does not necessarily lead to the other. Television is available to all through the increasingly advanced findings and experimentation of many decades of scientific activity in electronics. Understanding the nature of what we believe to be the **electron** is the culmination of the evolution of the atomic theory beginning many years ago, and which is still incomplete today. However, it was not an increased awareness and understanding of such theoretical entities as the electron, and other components of the atomic nucleus, which motivated the technological invention of the television; it was much more than a scientific discovery. Another example is that of the cellular phone; **the** status symbol of the 1990s. It is the culmination of many scientific principles of chemistry and physics and the price tag is high. Was the cellular phone invention the direct result of the process of science or was its invention motivated from something quite different? Yes, scientific knowledge and understanding are essential in order for this invention to take place, but can they be considered to be the impetus which is responsible for the technological breath of life resulting in this unique telephone system: Also it is not obvious that the inventor or inventors of the cellular phone had a detailed understanding of the scientific principles involved in order to arrive at this popular invention. The incorporation of scientific laws and principles is **in nature** quite separate from society's desires "put into practice" by the means of a technological invention.

Bernard Cohen, from his book Revolution in Science uses the example of DuPont which developed a lucrative research program which resulted in a vast number of new products. Purposive chemistry is presented as an example of technology deliberately setting out to creat, through a knowledge of specific chemical reactions, various dyes which were in demand. Here, according to Cohen, is where science shows its technological power. Technologists see a need and purposely set about meeting that need, putting into practice scientific principles. These same reactions, however, need not be used for the source of colourful dyes but are also available for use in many other areas of research and development.

We understand nature through science but deal with nature through technology. It is science that studies the happenings of the world around us, it is science that develops and redevelops theories and hypotheses about the processes which are occurring continually within our world. It is within the realm of science that the nature of understanding of life is ignited. Science is, for the most part, pursued and advanced in a rational, progressive manner; but it is really the "opening of that window of knowledge and looking out beyond one's own world" which science is involved in. It is the actual process of pursuing and advancing scientific knowledge which is inherent within the nature of science. Yes, there is pursuing and advancing of knowledge within the nature of technology as well but the context is different from that of science and so is the knowledge component. Knowledge and understanding of natural science take place in the academic realm of both the concrete and the abstract. The abstract is often brought into focus within the concrete world, as in the process of technological knowledge and understanding, but even the concrete world of natural science is not something one can "invent," it is something which is naturally there. So in this sense science is predominately in the world of the abstract and abstract ideas - even though they indeed stem from the concrete, visible world of human observation. Technology takes this abstract world and puts it into practice - it produces desired "effects," an experimentation of a sort.

Technology **utilizes** this knowledge and understanding.

However, as hinted at earlier in this chapter, technological inventions involve much more than science. The gap between science and technology is produced because one does **not** lead automatically to the other and the route which technology takes can vary extraordinarily depending on the current demands of society and the agreement among those involved that funding should be directed towards a specific project. Technology picks and chooses which scientific principles it will manipulate into a practical invention for the "good" of humankind; the scientist has already completed the **real** testing. Science unlike technology, advances regardless of society's approval for the most part.

Numerous currently accepted theories of chemistry and physics are applied continuously to the Fort McMurray oil sands at two major plants. Oil embedded in sand is extracted from the ground, separated from impurities and processed to "perfection" through the application of pure scientific principles. Does the understanding of the one lead to a greater understanding of the other? A **recognition** of the usefulness of the application of particular chemical reactions adds a relevance to the present grade 11 chemistry course. A **study** of this application, however, does not fall in line with a study of the nature of science. Many say that errors and problems in a particular technology are discovered too late; irreparable and often irreversible damage is done in the meantime. Is this also true of science? Anomalies in science can be regarded as tools towards further advancement. Karl Popper would encourage the production of the most innovative and testable conjectures as it is through the examination and possible refutation of these often erroneous ideas in which a great deal of information is rejected, but that much new material is examined in a new light. It is through the process of recognizing and searching out errors and problems which science often progresses. The responsibility to society and public welfare is not implicit in scientific progress as it is in the concrete world of technological advances. The technologist makes a choice among many theories and laws which he or she will develop and has a practical problem to solve. It is within this choice that the responsibility for the public good lies, not in the advancement of knowledge.

Science used to be valued as a means of getting to **know** the world; now, owing to the triumph of technique, it is conceived as showing how to **change** the world (Russell, p. 98). From the perspective of technical philosophy it is worth taking a look at the writings of John Dewey. His philosophy derives its inspiration from science in many ways. Firstly, Dewey points out that scientific theories change from time to time, and what recommends a theory is the fact that it "works." A Deweyan theory is a tool which enables one to manipulate raw material. It is judged to be good or bad by its efficiency in its manipulation. Secondly, science is to be admired because it gives us power over nature, and the power comes wholly from technique. Manipulation of science, then, can lead to the occurrence of technological power? Science achieves its ends within Dewey's "warranted assertibility" (Dewey quoted in Schwab, p. 68). One needs to be concerned with the conclusions of science, according to Dewey, for practical purposes. A societal need demands the application of science through technological devices.

> Pragmatism appeals to the temper of mind which finds on the surface of this planet the whole of its imaginative material; which feels confident of progress, and unaware of non-human limitations to human power...but for those who believe that life on this planet would be a life in prison if it were not for the windows into a greater world beyond...the pragmatist's world will seem narrow and petty (Russell, pp. 102-105).

It is only through the windows of pure science that men and women can explore and begin to understand the "theoretical entities" of science which constitute the higher levels of scientific understanding. Scientific knowledge and understanding are certainly verified and advanced when a theory appears to "work." However, it does not necessarily follow that because a theory's "testing" appears to be successful that it is limited to being a tool for manipulating material. That science can be utilized as a foundation of principles and ideas from which to bring to life ways of manipulating raw material does not mean that this is what science is limited to. For example, I may be successful in preparing and serving the most delicious peach pie that you have ever taster (although this is highly unlikely). Does it follow that a peach is defined as being the ingredient for a peach pie? Does it mean that my understanding of the world of peaches is complete and that what I believe a peach to be is now validated by my successful application of it? Furthermore, is the peach that I can observe, feel and cook with all there is to this world of peaches? I determine the "worth" of the peach by how successfully I can put it to use, is really what Dewey is saying. That is, the only thing to understand about science is essentially the current test. Studying the results of the test, without a knowledge of the principles of science is similar to the study of technology within a science class.

A theory does not have to consistently work to be of value as a theory. For example, the phlogiston theory **appeared** to work and contributed much to scientific research of the period. Observation and examination of evidence were occurring; the processing of science was alive and well. Even though today's scientists would disapprove of the phlogistic interpretation of evidence, they would not go so far as to say that the theory was not a valuable one. John Dewey refuses to separate pure science from the application of those hypotheses and laws. It is not an understanding of application which leads to a comprehension and appreciation of theory; it is an understanding of the theory itself.

The Nature of Technology

In order to analyze the nature of technology, a description and understanding of a particular example would be helpful. The primary technology utilized in Alberta, Canada is that of the hydrocarbon industry. Senior high chemistry has examined the actual extraction and break down (catalytic cracking) of long hydrocarbons into smaller, easily utilized ones on a superficial level - the processing has been left untouched. The actual chemical procedure is left untouched in the curriculum.

Many energy resource companies invest a great deal of their Canadian business dollars in Alberta; for example, Nova, Esso, Cabre Explorations and Norcen. The following figure of a natural gas processing plant is an example of a typical plant of any one of the aforementioned companies distributed throughout Alberta. The purpose of the gas plant is to prepare the natural gas, that flows from beneath the Alberta soil, for sale. Three major processes occur within each preparatory cycle - "dehydration," involving the removal of water which is absorbed by glycol; "refrigeration," a cooling process for the removal of liquid petroleum gases, and "compression" generally involving reciprocating compressors - a change in pressure to the equivalent of the "Nova" distribution pipeline system.

The motivation for these technological processing natural gas plants is multifold. Firstly, there is a need for the consumer for a readily available, relatively economical energy resource. Secondly, the supplying of this fuel to the consumer is one way of meeting another need - that of earning a living for the owner of, and those employed by, the gas company. Thirdly, science has made it possible, through an understanding of many complex laws of chemistry and physics and their interaction with each other, to undertake this natural gas extraction and processing. Therefore, in order for this technology to go ahead there must be a need for it, sufficient evidence that this need is a realistic one, proof that the technology is already in place in order to fulfil this requirement, a consensus among all relevant personnel that the chosen technology is the best solution towards meeting the acknowledged need, and sufficient financial backing for the project.

To further understanding of the technology described I would like to pull out a few scientific processes from the complex interactive process of preparing natural gas for consumer usage. Some of the applicable laws of science which are utilized in this Alberta technology are: a use of phase changes to purify material, the kinetic theory of gases and the relationship between pressure, temperature and phase change, and the intermolecular forces (vanderwaals forces) which affect the boiling points of the various light hydrocarbons.

The finding of an economical yet effective refrigerant is crucial to the success of any natural gas processing plant. In 1937 Thomas Midgley began a purposive research program to seek out a refrigerant with three essential criteria - a boiling point between 0 and -40 degrees, stability, nontoxicity and non-flammability. Midgley "turned the table on refrigerants," that is, he examined the arrangement of elements within the periodic table in order to find atoms which met the required criteria. He realized that flammability decreases across the table from left to right and that toxicity decreases as the elements proceed from the heavy metals at the bottom of each column (family) to the lighter elements at the top. From this understanding of the elements in relation to atomic theory, Midgley was able to focus on the atoms of carbon, nitrogen, oxygen, fluorine, sulphur, chlorine and bromine as probable candidates. All present day refrigerants are a combination of two or more of these elements. Freon has developed as a trade name for one of such compounds which are used to absorb heat and these were discovered through an analysis of the periodic table. It is through the cooling of the natural gas that the hydrocarbons from butane to heptane undergo a phase change from the gaseous state to a liquid state and separate out. It is essential that refrigeration engineers are familiar with the liquid-gas phase changes used to transfer heat from one space to another.

It was discovered very much later that the Freon gases (known as chlorofluorocarbons) tend to drift slowly to the upper atmosphere and are dissociated by the ultraviolet radiation from the sun and chemically react with ozone and destroy it.

$$Cl + O_3 \text{ ---> } ClO + O_2$$
$$ClO + O \text{ ---> } Cl + O_2$$

For each chlorine atom which reacts tens of thousands of ozone molecules are destroyed. Many of the natural gas processing plants are using ammonia (NH_3) or propane (C_3H_8) for their refrigerants instead of Freon because of its ozone depletion potential.

As seen in the above example, technological disciplines preserve enough unity and continuity to warrant "specific" status. Each specialized sub-discipline defines its own boundaries and direction of development in correspondingly specialized goals, such as the least possible "noise" or the greatest possible compactness, the highest possible reliability, directionality or security. The established repertory of practical knowledge - commonly referred to as **"state of the art"** - comprises the most advanced set of techniques whose proven reliability is currently accepted by professional practitioners of a discipline (Toulmin, p. 365). The collective task of systematically improving this repertory is the "thread around which the corresponding technological profession crystallizes; and this commonly comprises an international circle of expert devotees - whose members are in close personal contact, study each other's work, and engage in a **respectful but competitive** rivalry" (Toulmin, p. 366).

Technology, then, advances collectively within the context of international access to information and international dialogue, where technologists present different viewpoints, discuss critically and come to some consensus. But on what basis is this consensus founded? Technological progress advances knowledge and understanding directly and indirectly.

These are some of the limits placed upon the advancement of technological invention and which contribute to the separation between the progress of natural science and that of technology - technology requires the "go-ahead," to a greater extent than science, from a community of relevant individuals and groups and this "go-ahead" is based upon many practical concerns - the outcome of the technology must be fine-tuned to the place where it will be considered "state of the art," and yet not be potentially threatening, at the present or in the future, to an individual, society, or the environment. There appears to be a different motivation for advancement in technology than in science.

Crafts and technologies have developed to serve common human needs with more effective and useful goods or materials, equipment or services; they are concerned with the problems which arise in designing, manufacturing, and distributing such goods or services; and their historical development can be described in terms closely parallel to those that apply to scientific disciplines (Toulmin, p. 394). The question remains, "Are they concerned **enough**?"

Toulmin describes a parallel in historical development between the **practical procedures of technology** and the **explanatory procedures of the natural sciences.** Firstly, just as science comprises theories and concepts having different degrees of generality, so in a technology one can distinguish specific, detailed applications of technical procedures to particular problems from more general methods and techniques, and these again from the most general and fundamental principles of design currently practised in the field concerned. For example, the term "circuit" is just as defining a feature of electronics in technology as the concept of "inertia" is of dynamics in science. From the above example, de-ethanization and de-propanization are specific features of the processing of natural gas, and "reciprocating" is a specific feature of the natural gas compression process. Both scientific and technological procedures exhibit general principles which are specialized in a rational manner. The advancement of each is similar in that variations are deduced from certain fundamental design principles (Toulmin, pp. 365-366).

Secondly, the "state of the art" in technology develops by the selective perpetuation of procedural innovations. There is inherent within both the practical procedures of technology and the explanatory procedures of science a gap between current ideals and the most advanced repertory of techniques and/or theories. Neither ever reach a true "state of the art" in that there is always a reservoir of technical and/or theoretical problems which need to be recognized, examined and possible solved. The current repertory of science and technology, Toulmin would affirm, comprises techniques and theories that have survived the selective professional judgments, the prejudices and tastes, and memories and forgetfulness of the technologist or scientist concerned (Toulmin, p. 367).

In one respect, however, the process of technological innovation and selection differs markedly from that in science and its advancement through theory choice. In the natural sciences, states Toulmin, the form of competition and selection is predominantly **internal** to the scientific profession, that is, in the realm of experimentation and discovery. In technology, this is much less completely the case. Technological innovations are appraised not only with an eye to "expert" professional considerations, but also they are exposed to demands of other kinds. These include a concern about those which arise in the patent-office, the market-place or the forum of public debate, rather than in the laboratory or on the test-bench. A worthwhile technological innovation, then, must not only be technically feasible, effective and suitable for regular production, but also original, competitive, and free from objectionable nuisances.

This **multiplicity of requirements** blurs collective disciplinary aims in the technological field; it increases the number of stipulations needed for innovation in technology to be considered worthwhile. As a result, an answer to the question, "What defines **progress** in technology?" is one about which there is frequently less agreement than there is in science. Advanced technology does not necessarily imply advanced science. Kuhn's community of shared values and attitudes seems much more relevant to the workings of technological efforts within a society than to that of natural science. Kuhn's "normal science" in a sense culminates in the views of the community in which it is working, and is dependent upon the beliefs, understanding and knowledge of what is acceptable as "true" science by that particular community. Science, in Kuhnian fashion, takes on a sense of mission in that many contribute to the whole concept of the current understanding of what is and what is not science.

Karl Popper, in the context of analyzing Kuhn's concepts of revolutionary and normal science, compared Kuhn's Normal Scientist, who busily and unquestionably works on "solving puzzles," to that of the **applied** scientist, in contrast to the critical thinking **pure** scientist (Popper, p. 53). All this puzzle-solving leads to is an increase in specialization which Popper affirms to be a danger to science and to our very civilization (Popper, p. 53). Advancement of scientific knowledge is unimportant to technology.

The Ethics of Technology

Paul Feyerabend would concur with Bertrand Russell in his contention that applied science or technology that in any way restricts the "happiness of human beings and their freedom" is to be avoided (Feyerabend, p. 207). One cannot determine progress in science until one comes to terms with the values that one should promote; the same is true for technology. Feyerabend contends that the "happiness and full development of an individual human being" is the highest possible value (Feyerabend, p. 210). Kuhn argues that whatever scientific progress may be, one must account for it by examining the nature of the scientific group, discovering what it values, tolerates and disdains.

Mary Midgely states that the highest purpose of science is to understand ourselves and our place in the universe.

> For what shall it profit a man if he gains the whole world and lose his own soul?

Monod speaks of the "soul" as an inquiring intellect. Does "freedom of science" mean that science should progress regardless of social considerations? Midgely affirms that "all science has outside connections," and that the initial framing of useful new concepts is itself co-operative work that needs many minds (Midgely, pp. 57-87). Midgely's description of scientific activity is close to the definition that Toulmin bestows upon technology.

John Passmore, in Science and its Critics, argues that in the case of technological innovation the consequences are independent of the "nature" of technology. "The scientist's heart is pure," and technology is neither "his creator nor under his control" (Passmore, p. 27). An argument could be developed for invention, and not science, being responsible for the extension of human's dominion over nature: the "know-how" as compared to the "knowledge that." Pure science attempts to discover general principles of the widest possible generality which evolve into theories and laws. Applied Science is dependent on the **laws** of some other science. Ever since the 16th century scientists have made use of artisan's skills to facilitate observation and an understanding of the world. Theoretical concepts from practitioner inventions have been devised such as Harvey's description of the heart being like a pump and Boyle's depiction of the atom as a billiard ball. In the case of "environmental blight" one can say that the villain is **invention** and not **science**? Technological inventions are **dependent on science** for their very existence. It has been argued however that there is a gap between scientific disvovery and technological invention. One does the creating, the other responds to a need or demand by society.

Where does this leave the inventor? The commitment to freedom of inquiry is held in contrast to a fear of possible consequences. What **risks** are we willing to take in the name of scientific freedom? Another aspect of this dilemma involves the contention that technological inventions "increase helplessness," because they are comprehensible only to an elite. They are certainly not utilized only by an elite! It is not in the realm of science tht choices are made which need to be examined for their ethical component. Decisions and actions which affect our universe, and those who live within, are restricted to the realm of technological advance.

Technology and Education

Can one reduce the bad effects of technology, such as the depletion of the ozone layer, by modifying the education system? Education promotes awareness; or at least it should. It is one of the junctions of education to prepare students to take an effective place in society. it is also a function of the educational system to cultivate critical thinking skills which result in increased awareness of our world. Once citizens of Canada become knowledgeable about the good and evil of technology will they make more informed choices? Is the manner in which science is taught in our schools today conducive to this objective, "critically-inquiring" curriculum?

In a world of revolutions of all kinds, an education as a preparation for meeting the demands of the radical change which is occurring throughout the world is essential for the survival of our society (Scriven, p. 173). On a continent of revolutionary technological advancement, with the resulting detrimental consequences, there should be schools which prepare our young to meet these challenges thoughtfully and effectively. Michael Scriven questions, "What knowledge, skills and attitudes would help a student when he [or she] faces a revolution in his [or her] own time?" We must demand a reasonable knowledge of the arguments for and against, for example, "environment contamination and conservation" (Scriven, p. 173). Leaving out the past issues will simply guarantee repeating old mistakes.

At one time the ideal that some science should be widely taught was viewed as an attack on culture and the training of gentlemen. However, Scriven is not so much advocating the teaching of the principles of science for our moral survival, but rather the teaching of the technologies themselves. He does allow for the teaching of such general facts as the greenhouse effect of the earth's carbon dioxide mantle and the effect of melting the polar ice caps. These are facts, he states, about the world which are crucial in assessing the effects of human modification of the environment through the use of nuclear energy or atmospheric pollutants. However, one does not need the periodic table, argues Scriven, in order to understand the facts of industrial chemistry that mean our children will face a fuel crisis. Perhaps, our earlier example of the discovery of a refrigerant by way of an understanding of the periodic table of elements might point out quite the reverse. In another example, Scriven writes that before teaching "basic physics" one should teach the facts about the planets and rocket travel that make coal mining on Venus impractical and antimissile systems nonsensical. Therefore, he is saying that science is not necessarily an essential component of the study of technology. If it were it would be impossible to teach technology without it. One can learn to utilize a technological device without. One can learn to utilize a technological device without a comprehension of the principles of science embedded within its operation. If technology can be made comprehensible to the average citizen without an understanding of science, how then does the teaching of technology contribute to an understanding of the nature of science? The teaching of technology would obviously add another dimension to the teaching of scientific principles and in many ways add that component of relevance, such as Scriven's example of the fuel crisis. But it is not an integral component of what science is and is therefore not necessary, possible detrimental and confusing, to the teaching of pure science.

The science of chemistry has been applied to the development of a chemical industry and, with microbiology, to the improvement of agriculture and medicine. The role of the technological for the scientist is not to be found in the actual developing and advancing of scientific theory, it is of use in the area of **testing**. This is of great importance to the Popperian, of course, but for the actual understanding of science, the technological elements appear to be too sophisticated and complex to play a strategic role here. It is from the perspective of a particular culture and society that technology is understood, as well as from an understanding of science and its methodologies. Similarly, one looks to society and its attitudes and values for an honest evaluation of and justification for the role of technology, one does not look to science.

In conclusion, the compatibility between pure science and technology is tentative. However, it is not clear that the inclusion of technology within a science curriculum will contribute to a greater understanding of the nature of science. This is not to say that the study of technology is not worth doing on its own terms. Psychology, anthropology, sociology, and technology share many of the same features as that of natural science but one cannot include them on this basis. They also would add an element of relevancy, but one still can not include them within a study of natural science. Time does not permit and neither does the nature of science. If science involves the recognition of and searching out of anomalies within current acceptable theory in the context of critical inquiry, the openness of the experimenter and theorist to honest dialogue with scientists and non-scientists with conflicting viewpoints **within a specific domain of science**, and an ever-expanding knowledge base **within the domains of science**, why don't we teach just that?

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Chapter Four

SCIENCE 10

COURSE RATIONALE AND PHILOSOPHY

Overview of STS Approaches and their rationales

The Society and Technology approach to science programming in the secondary school is proclaimed by educators as the salvation for the damaged reputation of the body of knowledge commonly known as "science." The "image of science" has fallen from its previous pedestal of admiration and awe to one of lowly disfavour and harsh judgment. Physics is equated with the bomb, chemistry with pollution, and biology with the potential horrors of genetic engineering. Science and warfare are linked in the minds of all citizens world-wide and the Persian Gulf War, which has recently erupted in the Middle East (commencing January 16, 1991) between Iraq and the United Nations, is being televised into millions of homes daily. The fears of the Israeli population, revealed through their reliance on gas masks and doors and windows lined in plastic sheets, attest to the horrors of scientifically sophisticated warfare. The fault is linked to those of us teachers who have somehow portrayed science, consciously or unconsciously, in this negative perspective. Furthermore, fewer and fewer students enter science-related faculties of post-secondary institutions. The interest in pursuing a career in science, for whatever reasons, is declining. Therefore, it is cried, teachers must show that science has much to offer to the individual and to the well-being of society (Perutz, pp. 54-56).

To the Science, Technology and Society (STS) advocates of science education our present system of science education is one of the teaching of factual knowledge and formulae. The STS is presented as **the** alternative. It offers the benefit of "facing" issues realistically and being able to intelligently (not just emotionally) deal with them (Lewis, pp. 57-71). It is essential that science teaching in the future must be seen in relation to the needs of society throughout the world (Lewis, p.65). Once students are able to recognize intelligently, and make decisions about, important issues which are affecting their lives, they will in fact be contributing positively to society.

In the chapter entitled "Changing to a Science, Society and Technology Approach" by P. J. Fensham from Monash University, Australia, the STS Movement is again presented as a response to the present negative image of science. It is a movement, Fensham states, which recognizes that there has been mismanagement of the use of scientific knowledge and, as a result, a more responsible approach is needed. He puts forward three dimensions for the social content of science education. The first is the **social nature of scientific work itself**. He elaborates by reiterating that science is the result of diverse activities of human beings. The second dimension is that of **social application of science.**

traditions, and in the social and personal life of the citizens of all countries. The third dimension is one of social ideology. As well as experiencing the applications of science, this aspect is intended to suggest that human beings can also assess the worth of various applications of science (Fensham, pp. 69-70).

This global trend reaches the United States, where Collette and Chiappetta have edited a book entitled Science Instruction in the Middle and Secondary Schools. In chapter 10 they present an analysis of the new STS emphasis and the rationale behind it. They begin by defining both science and technology. Science teaching is defined as that of teaching "definitions." Technology is defined as applied science which, when included in science education, translates scientific knowledge (mere definitions) to the benefit of humankind. Technology has its own body of knowledge and it is through the study of technology that students would capture the truth about the positive aspects of science - science, through its application, provides ideas and devices to improve the quality of life.

The rationale for the STS approach strikes a similar chord throughout the United States and in Alberta, Canada. It focuses on the importance of Relevance. Relevancy is obtained through an examination of social problems and the application of scientific principles and processes to them. Science teaching should begin, as Scriven would applaud, with the presentation of some current social problem, which is at least in part aggravated through the misuse of science, and be followed by an examination of alternative views about how it is possible to remedy the current situation through a positive application of some pertinent scientific principle or principles (as opposed to the negative application of science which produced the problem in the first place!). The future Science 10 program produced by Alberta Education meets this requirement through the presentation of content within two Learning Contexts of "Science and Technology" and "Science Technology and Society." Futhermore, Collette and Chiappetta believe that opportunities arise within this STS context for the science student to discuss beliefs and values. Informed decision-making comes to life in the science classroom through proposed solutions to "real" life problems (Collette and Chiappetta, pp. 235-238).

Arguments in favour of the STS approach to science education spring from numerous events and ideas. Yager, author of "A New Focus for School Science" in School Science and Mathematics journal, advocates that science must, as a result, be focused on social issues and what takes place in society. Bybee, author of many articles on the STS approach in the journal School Science and Mathematics, believes that the STS approach will restore the public's lost confidence in science education. Another writer on the perspectives on STS instruction, P. Rubba, states that the STS approach has the potential to provide students with essential skills that can apply to their everyday life (Collette & Chiappetta, pp. 235-237). Other approaches put forward for the teaching of science with an STS emphasis are the Values-Education approach through the presentation and discussion of controversial issues and the Moral Development Approach (Collette & Chiappetta, pp 236-243). Fensham reiterates the probable success of such programs as he affirms that in order to reform science education in the past educators have looked **inwards** for a solution. Rather, he believes, they should be looking **outwards** from science to society to see how science is applied (Fensham, p. 69). As it appears from the agreement of authors and science educators quoted in this paragraph, the STS approach to science learning is believed to put into practice this looking outwards towards society in order to create science lessons with relevance and social worth.

After all, science has **humanized** society. Women's liberation could not have succeeded without science, specifically in the area of contraception and household technology. For another example, our attitude towards the mentally ill drastically changed once a scientific understanding was achieved. It is through science that we can gradually "substitute reason for cruelty, prejudice and superstitions" (Perutz, pp.18-19). Therefore, it is believed that the STS approach provides the foundation for this illumination. The essence of science, it is believed, is to be discovered within its social component. That is, without the social element, science cannot stand. Just as applied science rests upon a foundation of natural science, so does the foundation of science itself rest upon its social context. The STS emphasis, through a presentation of this social component integrated within the science lesson, will humanize science. Once science is humanized and understood within its context of social failure and success it then has greater significance and demonstrable bearing on the lives of the students. Science becomes relevant and hence more understood? Did Lavoisier's research in chemistry spring from an enthusiasm produced because of the relevancy of hydrocarbon combustion to his life and the quality of life of the society in which he lived, I wonder, or was he intrigued with the process of scientific discovery itself?

Science 10 Course of Studies (Draft, Sept. 1990): An STS Approach.

The primary aim of secondary education in general, as expressed in the junior and senior high program of studies, is to develop the knowledge, skills and attitudes of young people so that they will improve their own lives and the life of their community (Alberta Education). Senior High school education is directed towards the preparation of all students for living responsibly in an increasingly complex society.

The importance of science education in general and the reason for the recent changes in Alberta Secondary sciences are found in the rapid changes in science and technology, and their effect on every aspect of the community. Science 10, soon to be officially introduced into the classroom in September, 1991, is designed, according to the educators involved, to continue the development of student understanding of the ways in which scientific knowledge is developed (Nature of Science), the interrelationship of science and technology, and the importance of science and technology to the students' lives, careers, and communities. (Community is mentioned at least 3 times in as many paragraphs in the Science 10 Course of Studies.) This chapter will examine closely these three aspects introduced in Science 10 - the nature of science, technology and science relationships and the interaction of science with technology and society.

The STS approach is put into practice through the organization of the science curriculum around integrative themes. Examples of these themes are given as major concepts, science processes, and persistent problems and issues. This integrated program intends to develop both the knowledge of existing frameworks and the **desire and power to create new** ones. Underlying this science program is the belief in a fundamental unity of thought in the enterprise of science and that the study of science should reflect the unity of nature. Scientific activities may vary in direction but not in methodology, because the fundamental concepts, skills and attitudes of science are common to all areas of investigation (Science 10 Course Rationale and Philosophy, p. 1). The unifying themes come from the content of science, from the nature of science and from the interactions of science with society and technology.

Another aspect of the Science 10 course is the presentation of **Learning Contexts**. Although traces of the STS component within this new curriculum can be found in all aspects of the Course of Studies, it is predominantly found within the Learning Contexts, which are displayed on each page of the Course of Studies, adjacent to the appropriate "Knowledge and Skills" item under the heading of "STS Connections." The two major themes of "Science and Technology" and "Science, Technology and Society" are defined in this new curriculum as the **Learning Contexts**, but integrated within the Course of Studies as **STS Connections**. Included within the theme of "Science and Technology" is an understanding of the interdependent relationships of science and technology, including:

> the functioning of products or processes based on scientific principles, the ways that science advances technology and technology advances science, the use of technology to solve practical problems. (Science 10 Course of Studies)

Included within the theme of "Science, Technology and Society" is an understanding of how both science and technology have a social context, including:

> the influence of the needs, interests and financial support of society on scientific and technological research, the ability and responsibility, through science and technology, that society has to protect the environment and judiciously use natural resources to ensure quality life for future generations.

The current draft for the Science 10 Course of Studies consists of four units of study. These include: Energy from the Sun, Matter and Energy in Living Systems, Matter, Energy and Change, and, lastly, Energy and Change. These four units supply the outline needed to step easily into such globally approved STS topics as ecology, pollution, resources and quality of life. These easily develop into the familiar sub-topics of social relevance in the science curricula such as more efficient use of energy, alternate renewable sources of energy (solar, wind and tidal), advantages and disadvantages of nuclear sources of energy for peaceful purposes, and water as a key ingredient for human health.

The content of the four units is divided into four vertical columns in the Course of Studies. From left to right the columns are entitled "major concepts," "science knowledge," "science skills," and "STS connections." The aspects of the nature of science are intended to emerge from the content included within the knowledge and skills column (Introduction, Science 10, Course of Studies). The social relevancy, stated as necessary as a foundation for the nature of science, is supplied through the learning contexts of society and technology, or science, technology and society.

For example, a Unit 1 major concept is "energy from sun sustains life on earth." A definition of photosynthesis is placed in the adjacent knowledge and skills column and under learning contexts we find "discussing the implications of global deforestation for the human race." In summary, we have the concept which is to be learned, described in one column, the specific knowledge component and skills which will be used in illustrating this concept to the student in the middle column, and finally a specific social application through which the teacher can illuminate, and increase the relevancy of, the knowledge and skills taught in the far right column.

I will now take a closer look at the aspects of "science and technology" and "science technology and society" as they are introduced directly into the Science 10 curriculum. Selecting an example from Unit 3, we see that it "investigates the changes in matter and energy that occur during chemical reactions" (Course of Studies). The **Learning Context** for this concept is given in the form of a background of examples of processes which use chemical changes to produce useful substances and energy (Science, technology and Society component). Concept 3.5 requires the student to identify the various types of chemical reactions. This concept is presented within the Learning Context of the identification of chemical reactions that are harmful to the environment. Here, of course, technology is the culprit with its significant contribution towards the destruction of the ozone layer and the formation of acid rain and the greenhouse effect (Again the aspect of science, technology and society).

Concept 4.3 investigates the properties of representative compounds and links this investigation with the knowledge that there are several synthetic chemical compounds that are beneficial to society, accompanied by a discussion of disposal problems related to used materials. To be considered as "environmentally friendly" products must decompose spontaneously to original organic remains. These fit into a "list" of several common compounds and acids that are hazardous to human health and the environment. On the other hand the technological/societal foundation is supplied by "listing" several synthetic chemical compounds that are beneficial to society. The desired relevancy and subsequent student understanding of environmental issues and accompanying impetus to take action on these issues is intended to be supplied through the listing of harmful and beneficial chemical compounds and acids. The learning context does not stop there, however. Also included in the teaching of this concept is the:

> outlining of safe methods
> for handling hazardous
> substances in the home.
> (Course of Studies)

Subject matter within the context of the "science, technology and society" component is obviously well covered in Science 10.

The "science and technology" aspect is included, for example, in unit #1 in the description of the operation of weather satellites in monitoring weather systems and the operation of radar in tracking thunderstorms. It is covered in unit #2 in the description of how developments in the technology of microscopes has increased our understanding of cell structure. It is clear that subject matter in relation to the above two aspects is plentiful within the Science 10 curriculum. It can truly be called a STS course of studies. The third aspect, however, which is to be covered is the nature of science. This aspect appears to be extremely weak.

I will examine a concept within Unit #3, which has the greatest potential of all concepts within Science 10 to explore the nature of science, and show that even here we find the limitations of this course of studies to be detrimental to the teaching of the nature of science. Major concept #5 of Unit 3 is entitled "Matter has a well-defined underlying structure". The knowledge and skills taught in conjunction with this concept are to "demonstrate an understanding that matter consists of atoms, ionic species and molecules by: (1) providing definitions, (2) indicating the relative sizes of chemical species, (3) describing the extent to which we are able to observe chemical species with modern technology, (4) describing the structure of the atom, (5) outlining briefly the contributions of scientists to our understanding of the atom, and (6) defining the terms: atomic number, mass number etc. In order to immerse this portion of "knowledge and skills" in an STS context, the concepts are placed within the learning context of the following: (1) knowledge of the structure of matter has led to an improvement in the quality of life and the destruction of life, (2) illustrating with examples how radioactive substances are used in molecular biology, and (3) contrasting the use of nuclear energy for peaceful purposes and in warfare. The emphasis placed on concept #5 of Unit # is obviously that of "science technology and society," not the nature of science.

The very structure of matter itself, then, is taught through the following action verbs: providing definitions, indicating relative sizes, describing relevant modern technology, describing the structure of the atom, outlining historical efforts and defining terms! The essence of chemistry, the mechanism of chemical bonding, is taught through definition, description and outlining. Can one discover the nature of chemical science through the memorization of that which is defined and described to one?

Criticism of Science 10 and STS

Science 10 and the Nature of Science

Hints of the nature of science can be seen throughout the Science 10 Course of Studies. At the beginning of each unit of the Science 10 Course is a description of how the Nature of Science is addressed within that unit. Unit 1 intends that aspects of the nature of science emerge from the knowledge and skills developed within. This nature of science component includes the role of empirical evidence in formulating and revising theories and models. It is illustrated through models used to explain forces of nature such as hurricanes and tornadoes (Overview, Unit 1, p. 5). In Unit 2 the nature of science is stated as being exemplified through the use of mathematics, to calculate surface to volume ratios and using this data to infer limitations on cellular processes (Overview, Unit 2). The Unit 3 introduction states that the nature of science is exemplified by examining the role of empirical evidence in the development of a scientific understanding of the structure of matter. According to the Overview written at the beginning of each unit, the above mentioned areas expose the student to the nature of science within the Science 10 course. I want to argue that even though the nature of science is said to be included in the aforementioned ways within each unit, that it is really not addressed at all in the Science 10 course.

A study of the nature of science is exemplified through an examination and participation in the progress of science, within a particular domain. The nature of science is found in proliferation - science progresses through making choices. Science 10 offers no choices. Current theories are examined in the context of their improvement and advancement over earlier, inferior ones. Indeed, often the earlier theories are not mentioned at all, or only in the briefest fashion. Science flourishes when there is a multitude of hypotheses in the field. Scientific progress is in the sensing of anomalies. The knowledge and skills column of Science 10 embodies only puzzle-solving activity. The societal and technological component does not detract from, but in fact magnifies, the puzzle-solving approach. Technology examines uses of current scientific theories. It tests and exemplifies that which is presently acceptable scientific doctrine. Technology does not promote inquiry; science is not advanced. It simply solidifies one's beliefs in one's current theoretical practices. Similarly, the placement of scientific theory, for example the atomic theory, within a social context embodying the usage of and dangers inherent within scientific knowledge (as STS Science 10 attempts to do), is again promoting the acceptance of scientific knowledge as it affects our lives today. Indeed the STS approach calls for the recognition of anomalies or problems. It then urges science teachers to use this problem as a basis for exploration into the world of science. However, the difference here between the nature of science and this societal emphasis is that the initial anomaly is a social one which is not solved by way of science. These problems demand a social solution. There is the potential here for inquiry but only in the direction of possible elimination or modification of the current application of currently acceptable scientific facts. There is no incorporation of critical inquiry regarding the nature of science itself: how scientific knowledge advances and how it is considered to be unique from other forms of knowledge.

Science 10 presents no mention of problems inherent within observation statements as a basis for both the confirmation and refutation of evidence. Evidence is evidence, it appears. The nature of science within the Science 10 curriculum remains that of positivism. According to positivism, meaningful propositions were either the analytic and essentially tautological propositions of logic and mathematics or the empirical propositions which express knowledge of the world. The only significant statements regarding the world were those based on empirical observation, and all disagreements about the world could be resolved, in principle, by reference to observable facts. Scientific hypotheses and theories which were neither analytically nor empirically testable were held to have no meaning at all (Schon, pp. 32-33). Why pretend science is something it is not, something advanced through induction, settled and confirmed for all time?

The nature of science is not addressed in this course. The scientific process is again, as in all preceding secondary science courses in Alberta, presented either through definitions and formulae or muddied with the added complication of the societal and/or technological aspects. Even the presentation of the structure of matter itself leaves out the nature of science and focuses on current theoretical content presented as a sure thing. The major concept, "matter has a well-defined underlying structure," is presented in the science knowledge and science skills columns through only the sterile processes of describing, outlining and defining. The nature of science would be better served by a study, and close examination, of the conflicting theoretical models of the atom. Specifically, a look at the evolution between atomic theories I and II and so forth. This inquiry could easily lead to an appreciation of the positive and negative aspects of previous atomic models such as those presented by Dalton and Thompson, as well as the current Bohr and Quantum Mechanical atomic theories, enjoying present day popular acceptance. It could also lead to the students' recognition that the ideas representative of the model of the atom are subject to change and improvement. Also, there comes the idea that the current model may be advantageous in the answering of some questions about the behaviour of matter, but is neither final nor all-encompassing. Old theories also had their own merit. This process then takes on the likeness of an actual experience in the practice of theory change and choice, that is, an experience within the context of the nature of science.

Relevance and Motivation

As an alternative to a "nature of science" emphasis, STS intends to supply a social relevance for the student which it advocates as essential for the production of scientists and informed citizens. Its intent is to provide that spark of interest which motivates the student to learn science (Course Rationale and Philosophy). I would argue that firstly, the material is not presented in a motivating, interesting fashion. The material is predominantly taught through listing and outlining. Again we enter the realm of the sterile science lesson - one lacking a spirit of critical inquiry of why the scientific knowledge accepted in the 20th century is accepted rather than some other scientific facts. Students are urged to come to terms with theories currently under research and be able to list and outline, that is, regurgitate, the major components of those theories. We the teachers accept it, it has been proven after all, so the students should accept it as well.

Secondly, there is no sense of the student examining evidence and being involved in decision-making. The only decisions open to the student appear to be in regards to whether or not the effects of the application of current theory (technology) are beneficial or not to society, and if not what can be done about it? This is not allowing for any contribution towards the nature of science in the classroom, it is an examination of current social problems. Related as they may be to the application of science, they are not directly related to the nature of science. Thirdly, the course does not in any way address the nature of science. This nature of science emphasis, as opposed to a STS emphasis, would indicate an all-encompassing involvement in the process of science. This is the key to providing increased interest and motivation in science. This experience provides much more relevancy, more interest and motivation than the STS approach described in Science 10. Webster defines being relevant as "having significant and demonstrable bearing on the matter at hand." We must look inside science itself for this significance. The nature of science is not approached through the use of definitions and lists or even through the sketching of one dimensional constructs of the atom, just as it is not found within a STS curriculum. Science is rational inquiry - new and better (not perfect) hypotheses and theories replace old ones through a recognition of possible anomalies and a deliberate seeking out of these anomalies.

Technology and society are outside of the realm of the nature of science. They are areas of close association with science, but not an integral part of scientific progress. Yes, Kuhn indicates a communal involvement, and this may be a factor involved during the producing of science, but it is not an integral part of the nature of science itself. Kuhnian science involves the puzzle-solving approach of producing upcoming converts to the current scientific practices, as well as research centred around these practices. A true nature of science curriculum goes well beyond this indoctrination to the realm of producing future scientists as well as future non-scientists with an understanding of critical, scientific inquiry which will be of benefit to them in the world of science and outside of it as well.

The Unity of Science

I will now take a look at another aspect inherent within the Science 10 course rationale which appears to be in conflict with a true "nature of science" program. This is the aspect of the unity of science. The Course Rationale and Philosophy of the Science 10 program uses an integrated approach. It is stated that the fundamental unity of scientific thought is emphasized by organizing the science curriculum around basic common themes. Students are expected to demonstrate an understanding of the key concepts and principles of science that transcend the discipline boundaries and show the unity among the natural sciences; including the themes of change, diversity, energy, equilibrium, matter and systems. This approach is motivated by the belief that there exists a fundamental unity of thought in the enterprise of science and that this should be reflected in the science curriculum, that is, the study of science should reflect the unity of nature (Course Rationale and Philosophy, page 1). Later in the same document is the statement, "by illustrating that the processes of scientific investigation are similar, despite the particular discipline framework, the unified nature of the scientific enterprise is emphasized." Similarly, emphasis on the positive scientific attitudes of critical mindedness, suspended judgement, respect for evidence, honesty, objectivity, willingness to change, open-mindedness and a questioning attitude, are declared to be threads that run through the entire science curriculum (Course Rationale and Philosophy, p.2). These are very thin threads indeed, although in theory they are intended to be an integral part of the course.

The unity of science is an interesting point. There is no such thing as the scientific method. For example, Graham Wallas has made an attempt to formulate stages of hypothesis generation. There is a scientific method established for the formation of hypotheses. These stages include preparation, which involves diligent study in the area, incubation, which is a resting time, and illumination when the new hypothesis comes to consciousness easily. These stages have been illustrated by Wallas to have been implemented in many successful hypotheses formulated by scientists (Martin, pp. 11-12).

But do these three stages constitute a method? Michael Martin questions whether stages 2 and 3 can be deliberately brought about and if not stages 2 and 3 cannot be part of a legitimate design to formulate a hypothesis. Is there a mechanical method to generate hypotheses and do we need such a method to be rational? The question of whether or not certain processes are more successful in generating a hypothesis than others also arises. Even if Wallas's stages seem to be the most successful it does not follow that going through these three stages is the best process by which hypotheses are generated. Even if they could be proven to be, do they accurately describe the way in which most scientists do come up with their hypotheses?

James B. Conant argues that there are only scientific methods as opposed to a scientific method. Many curriculum designers appear to believe that if you do not believe in one scientific method you do not understand science (Martin, pp. 42-43). Michael Martin and Joseph Schwab would counter that the ability to see the similarities among the sciences, and the differences between science and pseudo-science, should be considered as evidence of a person's understanding of science. The very nature of science which was examined in chapter one explains that for the naive inductivist or falsificationist there is one method which is defined as the scientific one. I fear that this is the direction the Science 10 course is headed. Through the stressing of the aspect of the unity of science, rather than the diversity of science, students are again encouraged to see scientific knowledge, and the activities which produce this knowledge, in a vacuum. I am not speaking of a vacuum produced through the removal of the societal and technological context, but the vacuum produced through the limitations placed upon the science student when taught to learn science by way of a particular direction - scientific inquiry is inclined to be de-emphasized and scientific indoctrination increased. In the looking for and recognition of common themes within the various domains of scientific inquiry, one learns again to see the world around one the way one is taught to see it.

However, the philosophy of science has progressed far beyond this point - Kuhn, Lakatos and Feyerabend would all protest this unity of science approach. It is unfortunate that teachers and curriculum designers and politicians, all involved in the constructing of these new STS courses, were not aware of the advantages of exploring the nature of science from a philosophy of science perspective. Then and only then would we see some revolution in science curricula.

Yes, there is a need for change. There is far too much definition and formulae teaching in the current science courses. Scientific knowledge has been mismanaged and has produced, and is still producing, harmful effects to humans and their environment. Our students are not leaving school with the skills to deal effectively with the decisions which must be made about the future of our planet. However, a change of attitude will not result from an examination of the guilty party - technology, or from a superficial approach to teaching science. A change of attitude towards anything will come when one understands and grasps for oneself the nature of that something. With an increased knowledge of the nature of science will come a decrease in the negative image one has of science and in the mismanagement of scientific knowledge, as well as an increased interest and motivation in the scientific process. Or, one could argue that even if a change of attitude did not arise, at least that attitude is the result of an honest, critical inquiry. A knowledge of science will come through an examination of the very nature of the scientific process.

The study of technology is not a realistic avenue into the study of science. Much of applied science is so complex only a small portion can be grasped and understood at the senior high level. Technology is related to the study of natural science, however, it is a way out of the study of science in the avenue of testing possible applications of the principles of science. Technology is one way of "testing" science. It is a way out of, not into, the study of science. It is an expansion upon the study of natural science. As in the example given earlier of the Alberta technology of the gas processing plant, one does not need to study the technology of the gas plant in order to understand the principles of science upon which it is founded.

Joseph Schwab illuminates the nature of science by advocating that students study pseudo-science. Schwab uses the example of communism. He argues that studying communism (i.e. looking within) is the best guard against communism. Does it not follow that if communism is a desirable political philosophy that the study of it would be the best way of eliciting an excitement and appreciation for it? Or at least one could argue that it would be the best way to arrive at an honest and intelligent appreciation for it. What Schwab is saying is that an examination into the nature of science, by way of recognizing the difference between the real thing and the counterfeit, is the key to a genuine understanding of science.

The STS approach to the Science 10 course has done nothing positive for the teaching of science education. On the contrary, the technological and societal issues have added distraction and confusion to the study of science. It has merely added more factual information and memory work without promoting the involvement by students in the scientific process. It does not promote thinking through the relationship of science and possible environmental problems, for example. It has simply tacked on to a framework of science knowledge and skills, some social studies.

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Chapter Five

A NATURE OF SCIENCE PROGRAM

When discovering that my teaching experience consists of predominately senior high chemistry, the usual reaction is one of two responses. Either I am told, "I could **never** understand chemistry," or question, "How boring! How could you stand to teach science?" The student too succumbs to a similar response when confronted with a chemistry course. "What is in it for **me**?" "When will I ever use this information again?" "How does this affect **my** life?" I will argue that the implementation of a science program with a nature of science emphasis has a more fruitful impact on, and is of much more relevance to, the life of the student than does the STS approach to science teaching.

The History of Science 10

Science 10 is being developed as a pre-requisite to the senior high science specialities of Chemistry 20/30, Biology 20/30 and Physics 20/30. It is an integrated course to include components of biology, chemistry and physics as well as other aspects of science. Science 30 is also required for entry into the new Science 20 and 30 courses, which will be offered over the two years following the introduction of

Science 10. The biology, physics and chemistry subjects have been developed and revised over the past three years in order that they may too cultivate an STS approach.

As discussed in the fourth chapter of this thesis, there is need of a change. It will be useful here to take a look at the science courses currently in classroom practice. I will single out chemistry, as that is the course I am the most familiar with. Success in the presently taught chemistry 30 course is found in a memorization of details of electrochemistry, acids and bases, and energy changes, as well as mastering fixed equations for problem-solving which are essentially the same over all three units. Diploma exams for all "30" courses provide the incentive and motivation for the majority of students to become familiar with and regurgitate required material. We, as teachers or students, do no **have the time** to be enthusiastic about science!

I am familiar with the history and productivity of the chemistry 20/30 sub-committee, as I have served on this committee for three years (1986-1989). It is the same as the many other sub-committees formed by Alberta Education for the new science 10/20/30, physics 20/30 and biology 20/30. Each committee consisted of practising teachers in Alberta, rural and urban, a representative from the Evaluation Branch, the Alberta Correspondence School (now Distance Education) and a post-secondary institution such as NAIT or University of Alberta. Each of the committees was headed by the coordinator of senior high sciences for Alberta Education. These various committees usually met two or three times a year for three years, often at two-day stretches to begin anew and possibly redesign the various science courses.

Reception of STS Science in Alberta

There has been a great deal of vocal dissatisfaction throughout Alberta regarding the STS emphasis of the new science curriculum. Details of the new courses, as well as response guides, have been mailed to all high schools in Alberta periodically throughout the three year period in order to provide information and receive feedback from teachers and administrators on the progress of the committees. As well, at teachers' conventions there have been seminars presented by the science staff of Alberta Education in order to gain support for the new program. It seems, from my experience, that the more the teachers hear about the STS approach to science education, the less they want any part of it. The more the University of Alberta hears about the STS science curriculum the less this institution is in favour of it.

Many advocates of the STS approach say that the problem is very simple to define - teachers do not like change. Albeit there is truth in this statement, I feel the problem goes much deeper than this. Science teachers of Alberta know here is a problem with the current curriculum. Many struggle with the kind of teaching and learning which must take place in order to finally present the grade 12 student with a diploma exam and offer them success with it. It is mostly only definition and formula memorization which can be effectively tested the way our present evaluations are implemented. At least there is no room for critical questioning which allows enough room for a student to express what they have learned science to be. However, most science teachers are reasonable enough, even though it would mean a great deal more work for them in preparation time, to embrace a new curriculum which offers an improvement to the study of science. Simply because they are not happy with the current science courses does not mean to say that a possible alternative is the STS approach. As discussed earlier in this thesis, the only real alternative to the current practice of high school science is a program that really teaches **science**. The only alternative is a philosophy of science approach rather than an STS one.

A Nature of Science Program

The new Science 10 Course of Studies teaches students the art of memorizing and accepting that which the current texts deem as appropriate and acceptable scientific theory. It also encourages the reinforcement, rather than a critical evaluation, of those beliefs through the use of experimentation. There is, however, some potential for the nature of science to emerge. In order to demonstrate an understanding of matter, for example, the course of studies emphasizes how matter is classified on the basis of properties by using observation and experimentation to classify matter (How? Just the way we have always shown you, of course) and by the introduction of chromatography techniques (Unit 3, pp. 20-21). These potential tools for discovery are already comfortably settled in established theory and, although useful for the student in undertaking the process of science in the laboratory, still need to be clarified in the same light as the theory does, which is the foundation of the technique. Neither is settled and sure, neither theory nor technique should be taken for granted by the student as being settled or sure. Experiment is utilized in this course as the process of "setting up" in order to produce the results which were predicted in the first place, by both the teacher and the text book. Therefore, even when the "knowledge and skills" content approaches the issue of the nature of science, the implementation of teaching this content works in the opposite direction to the nature of science.

The question may be asked at this point, "How can one argue with experimentation, at least one cannot go wrong in this area of the **process** of science?' A way of clarifying my point is through the indication of how experiment works in "real" science. Of course, the role and interpretation of experimental evidence in "real" science differs with the different philosophies of science. The ideal conditions for scientific progress in the laboratory, as backed by Popper, Lakatos and Feyerabend, include an experimenter who has some hypotheses and theories of his or her own but is not blinded by them. He or she freely experiments for evidence for or against the orthodox perspective and interprets experimental results with an open mind.

A knowledge of the philosophy of science by curriculum designers producing the content, and science teachers putting the curriculum guides into practice, would have a positive impact on how the process of science is conveyed to students who will be fulfilling the role of future citizens, scientists or both. Many teachers and educators from high schools and universities realize the importance of such a reversal happening in science education. I would like to examine some of their ideas in the light of possible implementation into classroom science teaching.

Experiments in a Philosophical Approach to Science Teaching

Patricia Burdett, author and science teacher, is interested in active learning methods in school science and in introducing ideas from the history and philosophy of science into a school science setting. In a recent article she presents the topic of the "N-ray affair" to be used as a **simulation** in the science classroom. The N-ray affair is a well known example of deviant science. Burdett advocates the idea of simulation to strengthen understanding regarding the history and philosophy of science. "The main aim of the simulation is to provide an opportunity for students to improve their awareness and understanding of issues about the **nature of scientific knowledge and theory** and **theory change"** (Burdett, p. 186). Note here that the aim of her simulation is **not** to improve student awareness on issues about the nature of technology and its effect upon society, but rather on the nature of science itself. There is some support for this integration of a philosophy of science approach. For example, the General Certificate of Secondary Education (GCSE) in Great Britain has presented recent criteria which direct teachers' attention towards more philosophical aspects of science. They propose "a chance to people science with episodes, anecdotes and case studies drawn from records of active science communities" (Burdett, p. 180). As opposed to mere story-telling, Burdett's students are **actively** engaged in thinking about science and scientific theory, just as the GCSE suggests.

The historical background, forming the basis for this simulation, involves Rene' Blondlot, and his colleagues at the University of Nancy, who developed a research program around N-rays. Many scientists, working separately, discovered anomalies with the research program, yet it held on for a long time before it was finally abandoned. The N-ray affair raises issues about the reception of novel ideas and theory change (Gould quoted in Burdett, p. 186). Their mistakes may be shown to have arisen because contextual factors were allowed to influence their interpretation of observations and experimental results, "leading to deviation from accepted norms." Gould calls this "unconscious finagling." In his Mismeasure of Man, Gould describes this process as a researcher being so "guided by his or her preconceptions that inconsistencies in results, omissions and miscalculations bring about desired conclusions" (Burdett, pp. 187-8).

Students can experience this integral part of the nature of science through role-play of the main characters involved on each side of the issue. They can begin to see through different eyes. "What you see is what you get" turns into "What you expect is what you get." Burdett's article, entitled "Adventures with N-Rays: An Approach to Teaching about Scientific Theory and Theory Evaluation," presents a very detailed and enlightened approach to teaching science through this particular event of historical science. She gives some excerpts from the simulation transcripts used in the classroom and presents some idea of the sustained and absorbed nature of much of the role-play. As a result, Burdett gives a glimpse into the potential for teaching a nature of science curriculum (Burdett, pp. 191-203).

Colin Gauld, Senior Lecturer in Education at the University of New South Wales in Sydney, Australia, is involved in the education of science and mathematics teachers. He has a particular interest in the role of history and philosophy of science in science education. Gauld actually performs an experiment on his students. He makes a comparison of the children's beliefs with which they approach science issues and how these preconceived ideas influence the reception of new science material with that of the scientist's theoretical commitments and the influence of those commitments on the scientist's interpretation of what he or she sees.

Gauld used an electricity project to research his hypothesis. He examined the students' beliefs before and after a lesson on the study of electricity in a simple electric circuit, as well as a few weeks after the lesson had taken place. Gauld observed the following phenomenon. When empirical evidence conflicts with student ideas and supports the orthodox point of view it seems that many of these students at a later time give up the orthodox view it seems that many of these students at a later time give up the orthodox view and regress to their previous notion (Gauld, p. 63). Through the exposure of the phenomenon both teacher and students can examine the "issue of the reasons students give to justify their ideas and leads one to ask themselves what account they can give for their decision to reject ideas which they have admitted are more consistent with empirical evidence, in favour of ideas with which the empirical evidence is in conflict." Here is the philosophy of science in action. The students, if there is time allotted for dialogue between teacher and students about this phenomenon, should be able to begin to develop some of their own theories about themselves - what types of factors come into play in theory choice.

The philosophy of science focuses much attention on visual perception. To "observe" something is not the same as to "see" it. To observe implies close scrutiny or attention. Michael Martin speaks of the "phenomenological sense of immediacy," that is if someone observes that X is Q (for example, a white cloud is a stream of electrons) it usually **appears** to him or her that X is indeed Q. That the background and training of the observer affects what he or she sees is an integral element within the nature of science and is a "must" within the science curriculum.

Data from the experiments of Bruner and Postman support the claim that one's expectations may influence one to over look error and omissions when testing one's hypotheses through observation. Students should be aware, for example, that observation is not pure; it is selective, and that often theoretical bias blinds one to a theory's short-comings, and on the other hand, that one's commitments make one sensitive to certain problems. Here a presentation of the Popperian view of scientific progress would be appropriate in the promotion of discussion on the limitations of observation as a basis for the proof of a theory. A discussion to the effect that there is some value in the use of observation in forming hypotheses and that solutions to these problems can be found or at least looked for and thought about. This, I believe, should be the integral component of science education.

A Refocusing of Science Education

What our students of science, what curriculum designers, administrators, Minister of Education and his associates, and often scientists themselves need, is a **refocusing** of one's visual field. Refocusing involves observing a problem in a new way (Martin, pp. 104-111). The viewing of a new wet mount slide in biology class involves the starting all over again of the focusing process. One begins at low power, switches to high power and gradually brings into fine detail that which is deemed to be the essential ingredients of the slide. Perhaps science educators have been focusing in on the debris, rather than the integral components.

Besides the often explored aspects of the goals of education of knowledge, skills and understanding, there is one goal which fits in well here - we must develop within our students that tendency to behave in certain ways. It is in the agreement of what this new tendency should entail which needs to be refocused. In this case the development of a propensity towards that of a reflective participant. The three components of Dewey's reflective thought are those of open-mindedness, whole-heartedness and intellectual responsibility (Dewey, p. 6) Dewey promotes the idea of reflective intelligence for the teacher and student alike. Frankena describes John Dewey as the "apostle of the method of reflective enquiry" (Frankena, p. 143). Dewey speaks out vehemently against habitual and spontaneous thought. What should be habitual, Dewey claims, is the "use of intelligence." Reflective thought, or the continual refocusing of one's thoughts, opinions and actions, "means a habit of using the method of reflection whenever we sense a problem and of trying to sense a problem whenever there is one" (Frankena, p. 143). Science education needs to promote this reflective refocusing of ideas.

If science involves the recognition of searching out of anomalies within current acceptable theory in the context of critical inquiry, the openness of experimenter and theorist to honest dialogue with conflicting viewpoints, as well as an ever-expanding knowledge based of the world, then science involves looking for reasons. There is no looking for reasons in the new Science 10 program. The answers are given, the student's role is in simply committing them to memory.

The refocusing of one's visual field involves being open to new reasons. Students of science should be taught a number of theoretical approaches in a domain of research. If necessary, discarded theories from the history of science should be resurrected and reexamined. Students should not only be exposed to different theoretical approaches, but should also learn to work easily with different viewpoints, no seeing the domain from the point of view of one theory, now seeing it from the point of view of the other, switching back and forth to get various theoretical perspectives and insights (Martin, p. 125). Examples which would fit in the Science 10 curriculum are those of the Priestley and Lavoisier phlogiston/oxygen debate, mentioned in chapter two of this thesis. The exposure to the proliferation of theories in a given domain should make it less likely that one is blinded by one' commitments to any one of them.

This approach is also advocated by Harvey Siegel in his chapter devoted to "Science Education" from his work entitled Educating Reason. Siegel names it a "pluralist" science education. He draws together all the ideas inherent within a study of the nature of science in his pluralism. He describes pluralism as a "willingness to tolerate and utilize a diversity of ideas and approaches" (Siegel, 1988, p. 108). A pluralist science education is put forward for various reasons. Firstly, pluralism recognizes the fallibility of scientific knowledge. Secondly, pluralism recognizes the "virtue and potential fruitfulness of allowing rival ideas to establish their merits in the free exchange of ideas" (Siegel, 1988, p. 108). Both a pedagogical and philosophical point can be found here. Students become Schwab's "fluid" enquirers, committed to the habits of "reflection" (Schwab, p. 8).

Fluid enquiry involves the development and appreciation of alternative concepts and frameworks, as compared to "stable" enquiry whose function it is to accumulate what a doctrinal education teaches and to conceive this as the whole of scientific knowledge (Schwab, p. 15). The stable inquirer is pictured as Thomas Kuhn's "normal scientist," pursuing scientific experiments within a particular mind set. In contrast, the fluid enquirer portrays one of Kuhn's "revolutionary scientists" who recognizes the possibility of error with his or her particular paradigm and seeks out anomalies with an open mind.

Finally, pluralism may reasonably be thought to foster critical thinking in science students (Siegel, 1988, p. 110). Pluralist science education requires students to judge critically the merits of alternative claims, conceptions and perspectives.

> In helping a student, by way of pluralistic science education, to become a critical thinker with respect to science, one is helping the student to develop a **respect for reasons,** an **inclination to seek reasons,** and take them seriously as guides to belief and action (Siegel, 1988, p. 110).

The "role of reasons" in science can only be emphasized through a focus on the philosophy of science. The nature of evidence, the relation between evidence and theory, the evaluation of the strength of evidence, the role of evidence and reason in testing and in theory choice - these are all matters which bear directly on the nature of reasons in science, and which the philosophy of science takes as central to its concerns (Siegel, 1988, p.112). It is within the philosophy of science that a study of the nature of science emerges. Within the philosophy of science the aforementioned ideas are revealed through a refocusing of one's approach towards evidence, reason and testing. It is through these ideas that science must be taught in order to be called **science education.**

A Place for STS in a Nature of Science Curriculum

An examination of the reasons for introducing the Science- Technology-Society emphasis to the new Alberta Secondary Science Curriculum will help answer many of the questions which have risen regarding the appropriateness of this STS approach to the teaching of science.

The STS Approach Adds Relevancy

The aim of Science 10 is to develop scientifically literate and responsible citizens. The knowledge necessary for responsible actions is most effectively gained by students who are convinced of its relevance. In turn the STS emphasis in science education motivates students to learn about science (Science 10 Course of Studies).

To be relevant the material which is taught must be something that one feels like reaching out to and pulling into oneself. The student should not simply be able to **see** the connection but also grasp and **feel** that connection. It should inspire one to learn more. There is indeed a connection between science and applied science. It may be a pedagogical connection, and it is true that which I am interested in motivates me, but it does not necessarily follow that I must have an initial stake in the material being taught for my learning to be of educational value. It is possible that I can pick up this interest and detect the relevancy of the material along the way. This involves the discovery of a new relevancy: **science** and me.

The STS content of the Science 10 program is not added to the science content in a manner which would provoke interest. Even if it was of interest to the student, there is something to be said about the claim that the nature of science is just as relevant and even more interesting than the STS enrichment of the science program. We need not look outside of science to look for relevance. It is much more useful and convincing to look within, to the very nature of science itself as opposed to looking outwards to see how science is and could be applied.

I am not convinced that adding relevance is the answer to the initiation of student interest, motivation, and effective learning. I have spent many hours searching for relevant material in order to enhance the content for my chemistry classes. I began most classes with a reading and discussion of current social issues which I found in the Edmonton _Journal_, _Scientific American_, science sections of _Newsweek_, etc. I would allow five to ten minutes of the 80 minute period for this focusing on relevant social issues, and opportunity for discussion. Even the bonus "Question of the

Week," written up weekly on the side board of my classroom, had a technology-society emphasis. A good example is the net electrochemical equation and subsequent colour change which takes place during a breathalyser test at the police station. The equipment used to show the effects of the oxidizing agent (the dichromate ion) with the reducing agent (the alcohol!) could certainly be termed "technological" and the occurrence itself relevant to the individual and society as a whole.

My chemistry 30 course always included one class of formal debate on a subject relevant both to chemistry and current social problems. The question took the form of "Be it resolved that..." and two members either volunteered or were chosen to represent each side of the issue and were given minimal class time for research in the library. A panel of judges of either 3 or 5 was chosen to participate in the debate, as well as a chairperson. For greater student involvement the remainder of the class was asked to come prepared with an appropriate question, the time for which was allowed during a short "question and answer" period included before the closing rebuttals. The topics were chosen by the students themselves and voted on to select the one in which the class as a whole was the most interested. They usually decided on questions about the nuclear disarmament issue or the Swan Hills Waste Disposal Plant - "not in my backyard" controversy (Barrhead, where I was teaching, is en route to Swan Hills.) Student interest was generally high and there seemed to be a special enthusiasm when I videotaped the debates and played them back during the next day's class!

Other ideas I have incorporated into my chemistry classes that were actually outside the realm of teaching science, but which I hoped would add relevancy and thereby increase students' enthusiasm for learning, were numerous. It will briefly outline a few of them.

My "Lemon Tea" is the first idea to come to mind. During the Acid/Base unit of Chemistry 30 each semester I would take up an 80 minute block with a Lemon Tea. Equipment included a record player and classical music, a table cloth with which to cover my demonstration counter at the front of the classroom, and a coffee urn in which I heated hot water for tea. Materials included large yellow lemons, tea bags, styrofoam cups, sugar cubes, stir sticks (stolen from the staffroom) and some of my own baking (never overly popular). There were a few rules: one of which was that the students **must** have lemon in their tea, and secondly, the students must write a multiple-choice quiz. The quiz included such questions as: (1) Which is the "indicator" - the lemon, the tea or the stir stick? and (2) Who is the composer of the music you are now listening to? Was this Lemon Tea an academic waste of time? There was a chance to discuss why it was the tea, and not the lemon (which most students chose), which was the organic indicator which changed in colour when an acid (lemon juice) was added. Students left the class enthused about the Lemon

Tea, but had they **really** learned anything about science?

In chemistry 20 group work in the form of short 3-minute skits (also videotaped) was often used as a means of concluding the unit on chemical bonding. At Christmas time we sang songs like "I'm dreaming of a white precipitate" and I became inordinately famous for my "Cell Theory Rap" in Biology 10. I am not convinced that the biology students remembered or understood anything more about the structure and function of the endoplasmic reticulum than they would have had they been taught by a more traditional method. I wrote many songs on pollution and brought my electric piano to class and sang them, the students joining in on the chorus.

However, the most rewarding classes were the dialogues which resulted from a study of the actual principles of science themselves. These were of more interest and of greater relevance to my students than all my "entertaining" and determination to motivate could ever do. A thoughtful discussion of, and exposure to, the actual nature of science was far more what the students needed for a grasp of the true nature of science. These discussions resulted in a greater level of stimulation about science - **not** about issues which I, the teacher, felt to be relevant. Examples of these discussions centred around such topics as the difference between the chemist's and physicist's concepts of cathode and anode reactions, the anomalies often discovered in electrolytic reactions in the laboratory, Sir Humphrey Davy's perseverance in the discovery of the electrolysis of molten salts, and various conceptions of the definition of acids and how this theory changed over time. It is one thing to entertain; another to teach.

The Negative Image of Science

One particular song which our Biology 20 class sang now and then, which I did not write, is entitled Pollution.

If you visit Canadian city
You will find it very pretty
Just two things you must beware-
Don't drink the water and
Don't breathe the air!
(Pollution, 1975)

As discussed in chapter three, the evils of technology are real, relevant and related directly to science and scientific research. The mismanagement of scientific knowledge has undeniably contributed to the deteriorating state of our planet and surrounding biosphere.

J.L. Lewis in his article, "Teaching the Relevance of Science for Society," portrays the scientist as being cut off from the rest of society - dressed in a sterile robe of white, gazing at weird chemical reactions bubbling furiously and grasping strange equipment in his or her hand. The very image of the scientist then is a negative one. The scientist exists and functions in a social vacuum. "Perhaps we have enjoyed ourselves a little too much," Lewis cautions, "playing with ticker-tape, trolleys and our electromagnetic kits, or looking for evidence for the existence of energy levels" (Lewis, p. 58). There is another perspective and that is that scientists are perceived as gods- they are responsible for our new and wonderful mode of living. They have knowledge far out of reach of the average citizen, and this in itself can cause resentment or at least a feeling by the public of an accessibility to something which the average person does not have. This feeling of resentment, coupled with the well advertised "evils" associated with the application of science (for example, David Suzuki and gang) has, in many cases, resulted in a society with a negative view of scientists and their activities. Perhaps much of what we believe is linked to our experience and background - perhaps we need some of Martin's Refocusing.

The most effective way to take a realistic look at the worth of scientific endeavour is again to examine the nature of science -to get a glimpse of the essence of its research, not the applications of it. I do not look at the last page of a novel in order to assess its worth. I can only make an informed decision about the quality of story-telling by reading the book - chapter by chapter and page by page.

I cannot blame the violence and vandalism administered to downtown Edmonton during the evening of the Stanley Cup final hockey game on the Edmonton Oilers and how they play their game. In order to make a decision on the value of and gain an understanding of the game of hockey one must study the nature of the game itself. One the other hand, I cannot judge a novel to be good by its conclusion nor gain a realistic positive impression of hockey from positive post-game activities. In order to evaluate the worth of anything, good or bad, a close examination of the nature of that thing is the most reliable method.

"It was not nearly as bad as it **seemed**, once I actually did it!" The only way to combat the negative image of science, assuming one agrees that this is an important enough problem to design a new program around, is to dig in and **do** science. The assumption is being made that after a closer examination of science the student may feel that science is connected to that which is bad but that the process of scientific discovery is pure. At its worst it could be said to be tarnished, but still worthy of study.

The Student as an Informed Decision-maker

Responsible citizens students must be. The STS component of senior high science will go a long way towards producing graduates who are socially responsible. Assuming that it is one of the goals of science education to produce socially responsible citizens, the question still arises whether or not an STS approach to science is more likely to have such a desired result than is an academic, nature of science, approach.

To be an informed decision-maker one needs to divorce one's intuitive reactions from one's rational judgments, that is to understand that one's beliefs and experiences can greatly influence one's judgment and subsequent decision-making. Here is some more of Dewey's reflective enquiry. This opportunity can be placed in the context of controversial issues. The student must develop the skills to be able to examine, with an open mind, different sides of an issue and come to a rational decision. The student must be able to understand the reasons for his or her choice. The more practice he or she has at this exercise the better his or her chances of success later on.

Within the context of STS, social issues (for example, nuclear energy for peaceful purposes and warfare; industry/environment controversy are all I could find within the content of Science 10) could be examined in a manner in which critical thinking skills are utilized. In a nature of science program with a philosophy of science foundation, the focus is on developing this critical thinking within the context of science itself, not on the effects of science on society. It focuses on the development of reasons for one's decision-making and on an understanding of those reasons. A teaching of the science curriculum through an understanding of the actual process of science and its progress accomplishes two things: (1) an understanding and an appreciation for the use of reason in decision-making and (2) an understanding and appreciation for science. The goal of a critical science education with its focus on reasons in science through (a) the fostering of critical thinking in science and (b) the contrasting of genuine science with pseudo-science (for example, the importance of formulating testable theories and of considering all relevant evidence), (c) studying the philosophy of science and (d) by examining alternative theoretical perspectives and the reasons for regarding some as superior or inferior to others, is to be found in the study of science never being far from the consideration of the nature and role of reasons in science (Siegel, 1988, p. 113). We learn science and learn to make rational choices at the same time. Save the social and technological issues for social studies or align the science lessons to precede a social studies lesson on some relevant social issue.

In Conclusion

The proposed STS Science 10 encourages students to appreciate the practical impact of science on their lives and on society as a whole. It emphasizes an understanding of social issues needing attention - for example, water and air pollution, and the effects of chemical and nuclear warfare. STS advocates affirm that once students learn to face issues realistically and intelligently, and to deal with them, the result is the production of youths who are better able to contribute positively to society. STS offers a **relevance** via an examination of social problems and application of scientific principles and processes to them.

Science 10, with its STS connections, includes a study of compounds hazardous to human health and the environment, as well as disposal problems of used materials. (Unit 3, Course of Studies) The description of technology in current sources of energy and the merits of spending public dollars on investigating the atomic structure are studies also included within the STS_Connections column in Unit 3. (Draft, Course of Studies, p. 23) Is this not an attempt to present knowledge as relative to a specific paradigm? Our understanding of the atom is, for example, relative to how we put this knowledge to use within our current paradigm. Siegel would say that what Kuhn, with his relativistic epistemology, counts as scientific depends on the paradigm. (Siegel, 1988, p.107) This is an echo of Kuhn's statement that scientific knowledge is relative to one's paradigm, research tradition or conceptual scheme (Kuhn cited in Siegel, 1985, p. 102). What Alberta Education's STS science is, in essence, is a promotion of knowledge which is relative to our current paradigm. Providing society with informed decision-makers lacking the current negative image of science are two of the main goals of the STS science. This provides a narrowness of perspective and promotes an activity of science centred around current beliefs and practices. The focus is on the current research program - a study of science which Siegel names as not only uncritical but **anti**-critical. This science teaching involves immersing the student into the:

> current time-slice of the scientific tradition, including an appreciation of that tradition's standards governing the appraisal of reasons (Siegel, 1985, p. 104).

To be a critical thinker a student must be able to evaluate reasons. Reasons should be both "domain-neutral and "domain-specific" in order for the student to obtain a solid grasp of logical reasoning and a grasp of how reasons are evaluated in various domains. (Siegel, 1985, p. 104) Kuhn and his "normal scientists" would have us believe that what counts as a good reason for a claim depends on the paradigm one judges from. The STS science course leaves students with little else.

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